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Realistic Planning for Peace

IN the early days of the present war we emphasised the need for the careful planning of industry with a view to the prevention of the kind of chaos we experienced in Britain after the Great War. It was felt that this could be done without interfering with demands made on industry for the Forces. Those were the dark days when Britain was staggering under repeated blows by the enemy, and only a few were optimistic enough to speculate on the future. To-day, however, the position has changed, and our belief in ultimate victory has been transformed into a well-founded conviction. In consequence, the thoughts of responsible people are turned more urgently to the problems which peace will undoubtedly bring. It is important that this should be so, for events do not wait upon plans. As Mr. Edwin Fisher, of Barclay's Bank, said recently, our policy must be to achieve and maintain maximum efficiency in every department of national life. Full employment, which is Britain's declared policy and the ardent desire of her people, can be attained in the true sense only by this means, for effort ill-applied is but one step in advance of no effort at all, and can do very little to further the objects upon which our hopes are set.

There can be no doubt, however, that the future of Britain is beginning to take shape, fundamental factors associated with the brave new world of our dreams are gradually coming to light which seem to indicate that the reward for vision and courage, prepared in a stable and enduring form, is almost in sight. It is noteworthy, for instance, that Lord Woolton, speaking about the problems of reconstruction, assigns primary importance to housing, although he includes better education, a sturdy health policy, and work for all. Some time ago the Prime Minister gave us a useful slogan on the same subject: it was expressed as "homes, food and work for all." Obviously, the responsibility for producing the food, the homes and the work, when the war is over, rests with the Government then in power, but promises, substantial as they appear to be, should be supported by the preparation of adequate plans. Planning for the production of houses, for instance, cannot wait for the day of victory. It is true that much has been done, but progress is slow in defining the lines on which it can be made economically. Even in this section there are problems which bristle with difficulties, not the least of which are those connected with the location of post-war industry. There has already been a Report on this question which should enable

an amicable arrangement to be made so that the housing programme can be facilitated.

It must always be kept in mind that, whatever plans are made for adequate housing, their success depends on full employment, and here Mr. Bevin's Bill performs a very useful service. It establishes the right of men and women, now in the Forces, Auxiliary Services and Civil Defence Services, to have their former jobs back when they are demobilised. The Bill supersedes existing guarantees, and provides a new system to cover everyone, whether conscript or volunteer. It places on employers a legal obligation to re-engage former workers on demobilisation at the first opportunity that is reasonable and practicable.

In some cases, undoubtedly, disagreement will arise on what is reasonable and practicable, but the Bill meets this possibility by means of specially constituted committees. Thus, to deal with disputes, Reinstatement Committees are to be set up. These will consist of a chairman, employer's representatives, and a worker's representative, all selected by the Minister of Labour from a panel. Expert assessors will assist committees in hearing claims. The Minister of Labour will also appoint umpires to whom appeals can be made. Any organisation of employers to which an applicant belongs has the right of appeal to the umpires, and individuals may appeal if given leave by the Reinstatement Committee or if that committee's decision was not unanimous.

The Reinstatement Committees and the umpires have power to order an employer to make employment available, or to pay the applicant compensation, not exceeding the pay he would have received had he been re-engaged. The obligation of employers is limited by a provision giving preference to seniority in employment. No applicant can be reinstated if that would involve dismissing someone else who, before either of them joined the Forces, had been longer in that employer's employment. The right of reinstatement must be exercised by an application made within five weeks of the end of the applicant's war service, and application may be made either to the applicant's former employer or to the local office of the Ministry of Labour.

It is probable that this Bill will be criticised when it comes up for second reading, but it will be regarded as a real effort to simplify the return to industry of men and women who have been taken or have volunteered for emergency duties which have been considered to be of greater importance. The success of the measure, however, depends largely upon good will, and, apart from exceptional cases, there is little doubt that this will be forthcoming. The fact that it is the first really

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

concrete measure applied to reconstruction is worthy of note; it is a realistic plan, and in one important direction will assist in preventing one cause of chaos experienced after the last war.

The making of plans, provided they are realistic, is a good sign, but their success in overcoming post-war problems depends almost entirely upon a restoration of trade after the war that will provide the desired full employment. It should be remembered that Britain is dependent upon imports, and imports must be paid for by exports. Thus, we must build up our overseas trade

if we are to restore, let alone improve, our standard of living. The fact that, under the stimulus of war, secondary industries have been extended and developed in primary producing countries, does not reduce our difficulties, rather does it mean that our products and services may be expected to meet a growing rigour of competition as the deficiencies arising out of the war are made good. To give proper effect to reconstruction plans, it is necessary to use our skill and resources in the best possible manner in order to achieve the utmost economic production in goods and service.

Russian Industry Behind the Forces' Advance

IN following the marvellous advances of the Soviet Forces day by day in the Press we are inclined to forget the tremendous amount of work necessary behind the lines to make these achievements possible. While appreciating the supreme military skill which is gradually forcing the Germans out of the Soviet Union, without the whole-hearted support of workers in the factories and workshops the success so far achieved would have been impossible. A recent broadcast from Moscow gave some significant information on the admirable way in which the Soviet Forces are being supported by industry. Let us briefly refer to some aspects of this support, keeping in mind that a large area of the Union had, until recently, been overrun by the enemy.

During 1943 workers in the Urals produced from one-and-a-half times to twice as much ammunition and equipment as in 1942, and exceeded the State plan for tanks, guns, mortars and aircraft. It is claimed that output has been increased by the introduction of rationalisation, the increase of technical knowledge, and the adoption of an even-flow system. Although output has increased, there have been stringent economies in the use of raw materials. For instance, twice as much coal was mined from the deposits in the Urals, yet the electric power stations in this area saved about 100,000 tons of coal during the year, while the blast-furnaces economised to the extent of about 88,000 tons. It is noteworthy that during the year two batteries of coke ovens, tin open-hearth furnaces, new blast furnaces, steel rolling mills, and electric power-stations have been installed.

In the liberated Voroshilovgrad region mines are being restored day by day; in December last some 186 small pits were working, and five of the main mines were restored. Three days after the relief of Kiev the "Leninskaya Kuznitsa" plant was in operation, and was soon followed by others, despite the destructive efforts of the Germans on leaving the city. Then, although the Germans had tried to smash the main pit, within three days of their expulsion from the Donbas, this pit of the Kuibyshev Coal Trust had been partly cleared and was in working order.

In the Kuznets Basin 4,000,000 tons more coal were mined in 1943 than in 1942. In the iron and steelworks output of iron and steel increased by 70,000 tons, and by 73,000 tons of rolled steel. The production of ferrous alloys increased about three-and-a-half times. In the oldest-established iron and steelworks in Siberia, that at Guriev, output of alloy steels and of arms showed a big increase. In Stalinsk, in the Kuznets Basin, a fifth and last furnace has been built and put into operation at the ferro-alloy works, and high-grade alloy steels are

now being produced from local raw materials. The second section of these works was built in just about half the time taken on the first section.

It is apparent that considerable enthusiasm exists among the workers in the Soviet Union, which is reflected in the able manner in which they overcome obstacles to keep the front line men supplied with all the necessary aids to victory in the field. We admired them for their tenacity when a large part of their country was overrun, but it was to be expected that a nation with its back to the wall would expend tremendous energy to halt an invading army; they are to be admired the more, now that the Red Army is forcing the Germans out of the Union, for the splendid manner in which they are maintaining their support. Their magnificent efforts can be regarded as an example to the workers behind the armies of the other representatives of the Allied Nations. In the main it is not suggested that such an example is necessary, but in some directions there are indications of complacency which cannot be other than harmful to the fighting spirit of the nations concerned.

Price of Tin Increased

As from the beginning of this month the price of tin sold by the Non-Ferrous Metals Control has been increased by £25 per ton. The price for metal of minimum 99% up to under 99.75% tin content is now £300 per ton, and all other prices will be varied accordingly.

The previous price had been in operation since December 9, 1941. Since that date the cost of tin to the Ministry of Supply has shown a general upward movement, resulting in a substantial burden on public funds. The increase recently announced takes account of the present and anticipated level of costs of the supplies from the different sources available to the Ministry while the present abnormal conditions in the Far East continue.

Forthcoming Meetings

Institution of Mechanical Engineers

- Jan. 28. General meeting, at which will be given the Sixteenth Thomas Lowe Gray Lecture on "Fundamentals of the Marine Screw Propeller," by Professor G. S. Baker, O.B.E., D.Sc.
- Feb. 18. Annual General Meeting. "Fencing off Dangerous Parts of Machinery," by H. A. Hepburn, A.M.I.Mech.E.

Sheffield Metallurgical Association

- Feb. 1. "Any Questions." Members are asked to submit subjects for discussion.
- Feb. 12. "Some Electro-Chemical Methods of Analysis," by J. C. Gregory, A.Met.

The Hardening Quench

By E. Simister, B.Sc., Ph.D.

(Metallurgical Department, Kirkstall Forge, Ltd.)

In heat-treatment operations much attention is generally given to the heating phase, with relatively less attention to the equally important phase of cooling. The uniformity and character of the structure formed on cooling largely determines the value of the product, and this is mainly controlled by the hardening quench. In this article the author discusses the theory of quenching and various media employed, with their advantages and disadvantages.

THE first essential in the heat-treatment of steel is an efficient hardening quench. Efficient quenching relies upon cooling the mass of steel sufficiently quickly to exceed the critical cooling rate, so obtaining a uniform martensitic structure free from ferrite network or intermediate transformation products. The importance of this cannot be over-emphasised, as no amount of subsequent tempering will impart the best mechanical properties to a steel that has not been adequately quenched.

The main factor deciding the choice of quenching conditions is, of course, the hardenability of the steel. In general, it is desirable to use as mild a quench as is consistent with the production of optimum mechanical properties in the material, and one of the advantages of alloy steels is that complete hardening can be obtained with less drastic methods of quenching than are necessary for the plain carbon steels, so minimising cooling stresses and distortion.

The cooling media used for quenching steel are, in order of increasing severity, air, oil, water and aqueous solutions. Air hardening is limited to the high-speed tool steels and to the higher alloyed steels of the 2 S.28 class. Oil and water quenching are the two most frequently used methods. Aqueous solutions, such as brine or caustic soda, are also utilised, and investigators have claimed many advantages for them. Oil quenching is the most commonly used, but under present conditions, with the extended use of plain carbon steels and the lower alloy emergency steels, it may be necessary to resort rather more frequently to water or water-base quenching in order to obtain the desired mechanical properties, particularly where the mass or ruling section tends to be heavy.

The relative quenching powers of water and oil may be judged from the cooling curves in Fig. 1. These curves, reported by Stanfield, show the fall in temperature just below the surface when quenching 3-in. diameter steel cylinders.

Theory of Quenching

According to the generally accepted theory, when a piece of red-hot steel is plunged into a quenching bath, cooling takes place in three stages.

In the first stage boiling or decomposition of the coolant occurs, giving rise to an envelope of vapour around the metal. Cooling during this stage takes place by conduction and radiation through the gaseous film, and the heat transfer is consequently somewhat restricted. As the temperature of the metal falls the vapour film becomes unstable and finally collapses,

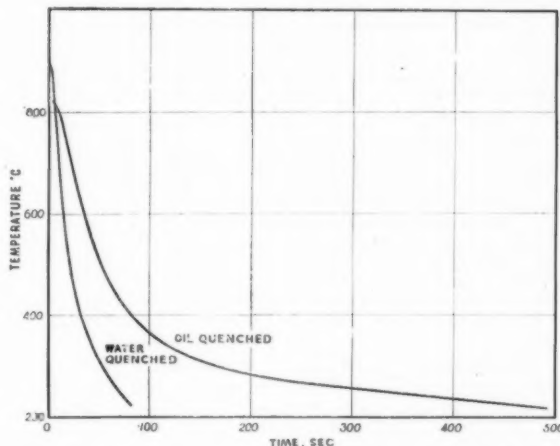


Fig. 1.—Cooling curves for steel cylinders quenched in water and oil (Stanfield 2nd Report, Alloy Steels Research Committee, 1939).

giving rise to a second stage during which vigorous boiling takes place. The latent heat of vaporisation causes the withdrawal of a great amount of heat from the metal, and in this stage the maximum cooling velocities are attained. Finally, as the temperature drops below the boiling point of the liquid, cooling takes place by conduction and convection. During this stage the rate of cooling is governed by the thermal conductivity and viscosity of the liquid.

These three stages are characteristic of liquid quenching, and the actions of the various quenching media differ from one another only as regards the duration of the different stages and the temperatures at which they become operative.

Water Quenching

Water is a most powerful quenching medium, and widely used on account of its low cost, availability and safety in handling. Its cooling capacity is considerably greater than that of oil, but the layer of water vapour formed in the initial cooling stage is somewhat unstable, and its irregular breakdown may give rise to uneven surface hardness. The danger of quench-cracking is increased by water, particularly with steels of higher carbon content, although it may be noted that with irregular sections quench-cracking is more likely to be due to non-uniform cooling rather than to too rapid cooling.

An increase in the temperature of the water reduces its quenching power to a marked extent. The following figures extracted from "Metals Handbook," of the American Society for Metals, indicate the influence of water temperature on the cooling rate over a specific range of temperature.

Temperature of Water,	Cooling rate relative to Water at 20° C. over the range 720°—550° C.
0° C.	1.00
20° C.	0.72
50° C.	0.17
75° C.	0.047
100° C.	0.044

It is a disadvantage of water quenching that the steel is cooled rapidly in the final stages—that is, when it is approaching the fully hardened condition. Raising the temperature of the water not only restricts the cooling rate through the critical range, but depresses the maximum cooling rate to a lower temperature when the steel is in its hardest condition and so greatly increases quenching strains. Warm water is consequently a far-from-ideal quenching medium, liable to cause soft spots and increase the danger of cracking.

The general recommendation is to keep water and aqueous-quenching solutions cold, preferably below 20° C.

Aqueous Solutions

The use of aqueous solutions as quenching media may appear to be rather limited in general practice; they do, however, find important application, and certain of them possess advantages which merit a closer consideration.

Solutions of caustic soda or common salt have greater quenching powers than water; the cooling effect is more uniform and less affected by the temperature of the bath; there is better removal of scale during quenching, and the general result is to produce a more regular hardness. The greater uniformity of action of these salt solutions is attributed to a reduction in the duration of the initial vapour stage of cooling.

Trembour and Scott showed that in brine baths optimum results were obtained with solutions containing 9% by weight of common salt (density 1.063 at 20° C.), and that at this concentration the incidence of soft spots was at a minimum. Similar results were obtained with a 3% solution of caustic soda. The corrosive tendencies of the salt solution as regards equipment should be watched, and a certain amount of care is required in the handling of a caustic-soda bath to avoid exposure to splashes.

The presence of a small amount of soap in an aqueous-quenching bath is most detrimental to the quenching ability. The effect is to greatly extend the duration of the vapour stage and cause soft spots. In view of this it is important to avoid any contamination by soap, such as may arise, for example, where a water-quenching bath is convenient for washing hands. Water carrying dissolved gases also is unsatisfactory for quenching purposes; maximum hardness is not attained and soft spots are formed.

Oil Quenching

Oil is the medium most extensively used for steel quenching. Its action is less drastic than that of water, and its cooling characteristics appear particularly suited to the heat-treatment of the deeper hardening steels. The cooling capacity of oil in the initial stages is somewhat less than for water, but is sufficient to exceed the

lower critical cooling rates of the alloy steels, and there is an important advantage of a much slower cooling rate in the final stage, as may be seen from Fig. 1. This reduced cooling rate takes place in a temperature range corresponding to martensite formation, with the effect of reducing internal stressing and so minimising the danger of quench-cracking.

Many different types of oil have been tried for quenching, and all appear to have their characteristic advantages and disadvantages. Of the two main classes of quenching oils, the mineral oils and the fatty oils, the former may be subject to volatilisation with a loss of lighter constituents, while the animal or vegetable oils in the latter class are liable to oxidation and sludge formation, and may be objectionable in use. Low resistance to oxidation is a particular disadvantage of sperm oil. All these changes result in some thickening of the oil and a consequent loss in quenching efficiency, although the deterioration is less in the case of mineral oils.

In addition to the two main classes there are also blended oils, which are generally mineral oils, carrying a small proportion of fatty oil.

With regard to the selection of quenching oils, they are, of course, primarily required for their cooling characteristics, but as these cannot be readily specified it is usual to rely on standard physical and chemical tests, and in this connection the following points may be noted. A high flash point reduces the fire hazard. A low viscosity assists circulation and convection in the bath and diminishes the oil loss by "drag-out" on the quenched steel. The volatility of the oil should be low. There should be good resistance to oxidation and sludge formation, and the oil should not thicken in use. A low saponification value indicates a mineral-base oil and consequent freedom from organic deterioration.

On the basis of chemical and physical tests it is difficult to assess the merits of an oil with regard to its quenching ability; but such tests are valuable in establishing the chemical stability and general serviceability of the oil, and carried out periodically furnish a check on the constancy of properties.

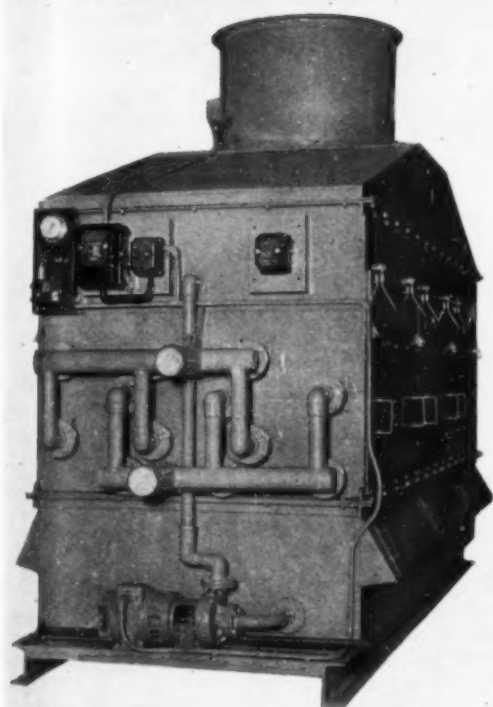
The following are typical properties for a mineral quenching oil as used in "heavy" quenching:—

Specific gravity (60° F.)	0.88
Open flash-point, °F.	385
Viscosity (Redwood), secs.	
70°	250
100°	110
140°	55
180°	40
200°	36
Saponification value	Nil

There is rather a large gap between water quenching and oil quenching, and many attempts have been made to introduce coolants of intermediate severity. Oil-water emulsions have been used in this connection but require care owing to their limited stability. A more probable line is the development of quenching oils by blending, and the addition of wetting agents, so as to increase the quenching rate through the hardening range, while yet retaining the advantage of slower cooling through the lower temperatures.

Oil-Temperature Control

As distinct from water, the quenching ability of oil is little affected by moderate variations in the bath temperature. Nevertheless, temperature control of oil-quenching baths is of importance in assuring uniformity of quenching action and a consistent quality of quenched



Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 2.—Closed circuit oil cooler, with evaporative spray cooling.

product. If the oil temperature becomes too high owing to ineffective cooling, or to using too small a volume of oil for the amount of steel being quenched, there is a possibility of uneven hardening. In addition, with the higher bath temperatures, more oil is lost by evaporation, due to its increased volatility, and there is a danger of fire. On the other hand, if the oil is cold its increased viscosity impedes circulation, so resulting in a less effective heat-transfer.

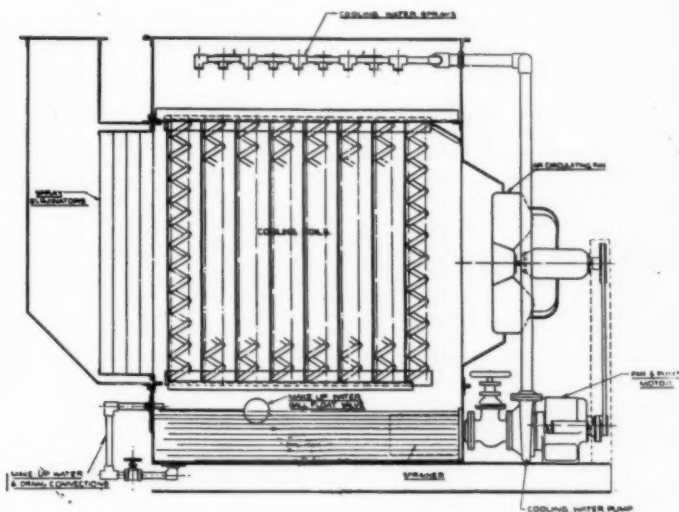
Generally speaking, oil-quenching baths function more efficiently if kept warm. The optimum temperature will depend upon the nature of the oil and upon the class of work, as well as upon the particular operating conditions. In usual practice oil bath temperatures range between 30° and 60° C., although beneficial results have been reported by using oil preheated to about 80° C.

To avoid over heating there must be an adequate volume of coolant both in the bath and in circulation. In deciding quench tank capacity it is usual to allow 1 gal. of oil for each 1 lb. of steel quenched per hour, and this rule may also be applied to water tanks.

There are two general types of oil-cooling systems. In one the oil is cooled by water pipes in the bottom of the tank, but in this case as there is no circulation of the oil, efficient agitation is essential for satisfactory operations. In the second type the oil is circulated from the bath through an external cooling system, which arrangement is to be preferred as being more efficient and enabling better control of quenching conditions. With regard to this second arrangement, various types

of oil coolers are available and deserve some consideration.

Where natural or forced draught is used for cooling, the method has the disadvantage of being affected by atmospheric conditions, and the cooling efficiency is liable to fall off in warm weather. In the so-called open-circuit coolers, where the hot oil is directly exposed to air cooling, there is always danger of oxidation and



Courtesy of Wild-Barfield Electric Furnaces, Ltd.

Fig. 3.—Closed circuit evaporative spray cooler with thermostatic control of quenching oil temperature.

sludging, with a consequent drop in quenching efficiency and a need for frequent renewal of the oil. This is an instance where a mineral quenching oil should be selected for its resistance to oxidation. A closed-circuit cooler is generally to be recommended. In some installations of this type the oil passes through a tubular heat-exchanger, where it is cooled by either cold water or refrigerated brine. An alternative system which lends itself to close control employs the evaporative water-cooling principle. In a cooler of this type, a working arrangement of which is shown in Fig. 2, the oil is circulated through a bank of cooling coils, where it is subjected to the combined cooling effect of water sprays from a series of atomising nozzles and a cross-current of air generated by a fan. This system can be arranged for automatic regulation of the cooling conditions so that thermostatic control of the quenching-oil temperature is possible. Fig. 3 illustrates a high-capacity cooler of the same type and fitted for thermostatic control of the bath temperature.

Influence of the Surface Condition of the Steel

The surface condition of the steel plays an important part in the process of heat-transfer during quenching. A heavy scale will interfere with the cooling action, particularly with the milder media, and may give rise to incomplete or non-uniform hardening. There is, however, some evidence that a thin film of scale is beneficial in so far as it assists wetting of the surface, a smooth, unoxidised surface tending to retain the vapour film.

The composition of the furnace atmosphere will be a factor controlling scale formation, and the conditions should be such as to avoid excessive scaling. It is known that sulphur compounds in the furnace atmosphere increase scale formation, and a low-sulphur fuel is therefore to be preferred. A few per cent. excess of oxygen in the atmosphere is not usually detrimental, and may be even beneficial as it counteracts the effect of the sulphur compounds, also the scale formed in a slightly oxidising atmosphere is less adherent, and consequently less likely to interfere in the quenching process. The question of scaling becomes more important when the article is to be oil quenched as then the scale is not so readily removed as in water or water-base coolants.

In considering the effect of surface condition, it is interesting to note the use of a thin refractory wash or "facing" mixture which, applied to tool steel, results in a greatly improved quench. The rate of cooling is considerably increased, and is quite regular as the usual cooling stages are suppressed. This action indicates the distinct influence of surface condition on the quenching process, and the particular advantage to be gained by reduction of the initial vapour stage of cooling.

Circulation of the Coolant

With any quenching medium good circulation and agitation increases the efficiency of the quench by removing vapour bubbles formed at the surface of the hot metal and presenting a continual supply of fresh coolant.

In connection with the cooling power of quenching baths, Grossman has published data enabling an estimation of the quenching power of commercial baths to be made. The following values, which have been obtained, in addition to showing the relative cooling powers of the various media, clearly indicate the marked influence of the degree of agitation of the coolant on the severity of the quench (heat-transfer equivalent). The actual values may vary in practice according to conditions.

Agitation.	Heat-transfer Equivalent.		
	Oil.	Water.	Brine.
None	0.3	1.0	2
Moderate	0.4	1.5	2.5
Violent	1.0	4	5

A point of practical importance in quenching technique is to arrange the relative movements of the metal and the liquid so as to avoid, as far as possible, the formation of vapour pockets and eddies on the "down-stream" side, as these will interfere with heat-transfer and give rise to soft spots. With hand-quenching, uniformity will be assisted by a "figure-eight" movement of the piece in the bath. In the case of bar shapes, a horizontal spinning motion during immersion will reduce warping.

Where a number of parts such as bars or small forgings are quenched together, there must be sufficient separation so as not to interfere with circulation of the coolant through the bulk of the charge.

In general practice circulation through the quenching bath is principally for reasons of temperature control of the coolant, and unless the system is specially designed

the velocity and degree of agitation will not alone be sufficient to give effective quenching conditions and some arrangement should be made to keep the steel in motion in the bath.

In some installations, in order to promote agitation of the coolant, the oil in circulation enters the tank at the bottom through a series of nozzles so directed as to impart a swirling motion to the bath. Another method is to use a propeller to drive the cooled oil directly on to the steel.

Probably the most effective method for securing a uniform and rapid quench is spray quenching by the use of high-pressure water sprays. The impingement of a concentration of high-velocity jets on the surface of the steel prevents the formation of continuous vapour films, and there is most effective contact between the liquid and the steel. This method of quenching is finding increasing application in surface-hardening practice, as spray-quenching fixtures can readily be arranged for localised hardening.

Special quenching machines, as used for gear hardening, give extremely uniform results and limit distortion to an absolute minimum. The gears to be quenched are clamped tightly between perforated dies, through which the quenching oil is forced under pressure.

The development of these mechanised quenching processes is an indication of the general trend of ideas with regard to the quenching of steel. The quenching operation can no longer be haphazard, but should be subject to careful control based on physical and chemical principles. Coolants should be carefully selected to suit the job in hand, and quenching equipment should be designed to meet requirements of circulation and agitation with effective control of bath temperature. Close attention to these various factors promotes efficiency and uniformity of quenching action, with a corresponding improvement in the quality of the heat-treated work. Apart from improved mechanical properties quench control minimises wastage due to cracking, and owing to reduced distortion many straightening and machining difficulties are avoided.

A New Method of Descaling

DEVELOPED for the rapid removal of rust and scale from all types of ferrous surfaces, J. V. Ruston (London), Ltd., make high claims for a descaler, which they market, known as "Rushcene." It is claimed to be both simple and economical to work and the procedure for using is the same as other pickling solutions—namely: The articles are first degreased either in an organic solvent or a standard alkaline cleaner or in both, rinsed well and then immersed in the descaler until all the scale is removed (this time being dependent upon the thickness of scale and temperature of the bath). After removal from the descaler they are then rinsed well in cold running water and are then ready for any subsequent treatment. If high carbon steels are being descaled (these are very prone to embrittlement and the time of immersion should be reduced to a minimum so as to minimise this danger) they may require brushing slightly after rinsing as there may be a loose thin carbon film left on the surface. It is claimed to give results superior to the standard descalers.

The Hawker Typhoon Single-Seater Fighter and its Napier-Sabre Engine

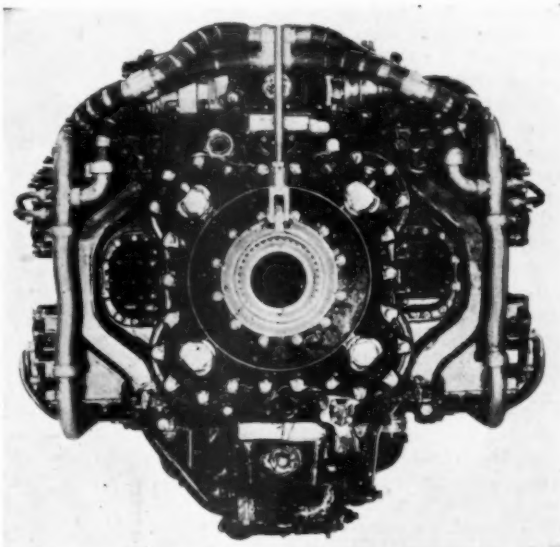
In the early days of the war it is well known that shadow factories sprang up in various parts of the country. These were equipped and staffed and, subsequently, put into production on vital war machines and parts with a view to building up the defensive and offensive strength of our Forces. We have been privileged to see one of these factories in the North-West, where Sabre engines are being produced in increasing numbers for mounting in one of the latest fighter planes, the Typhoon, and this brief description will be of interest.

THE Hawker Typhoon is the latest development of the long line of successful single-seater fighters produced during the past 30 years by the Hawker and Sopwith companies. Just as the Hurricane, one of the most versatile of all aeroplanes, was the outcome of many years of experience in the design and construction of high-speed types, famous among which were the Woodcock, the Hawfinch, the Fury and the Hart, so the Typhoon is the logical development of the Hurricane. The evolution of this latest Hawker fighter into the production stage has been influenced by the vast amount of knowledge gained on active service with the Hurricane in every theatre of war, and in all kinds of climatic conditions.

The Typhoon is a single-seater low-wing cantilever land monoplane, with retractable undercarriage and tail-wheel, designed for both day and night fighting duties. It is powered by a Napier Sabre liquid-cooled engine fitted with a left-hand duralumin-bladed de Havilland constant-speed propeller. There are two alternative types of armament, consisting either of 12 0.303 Browning machine guns or of four 20 mm. Hispano guns.

The first official mention of these new and formidable R.A.F. fighters came after the Dieppe raid in August, 1942, when they scored a considerable success. It was many months before the Luftwaffe knew what had hit them. Appreciably faster than Germany's latest, the F.W. 190, the Typhoon ranks highest among the world's fighters for combined speed and fire-power. This great fire-power has also been used for attacking ground and sea targets. R-boats, E-boats, coasters, merchantmen, barges and dredgers have frequently been victims of Typhoon attacks, as have locomotives, oil and fuel-storage tanks, airfields, factories and enemy troops. The Typhoon has inherited all the universality of its predecessor, the Hurricane. It can be fitted with long-range fuel tanks to increase its range, or it can operate as a fighter-bomber, with two 500-lb. bombs fitted under the wings. This has considerably increased its power as a low-attack aircraft, and has added weight to the daylight bombing offensive.

Recently, over Holland, Typhoons on patrol came across 19 Dornier 217 bombers, and shot down 11 without loss. On another occasion Typhoons shot down six F.W. 190's and one Ju. 88 over their own airfields in France without loss. There is no doubt that should the full weight of the Luftwaffe ever be directed against Britain again the Typhoon is in a position to repeat the victory gained by the pilots of its immortal ancestor, the Hurricane. As a weapon of attack, more will be



End view of Sabre engine, looking on propeller shaft.

heard of it when the offensive on the Continent is mounted from this country.

Structure

The structure is reasonably conventional in design, with the exception of the wings, which have been subject to special treatment in order to provide practical gun installation. These are tapered in section, and there is no centre-wing action other than the short members across the fuselage, the wings extending right up to the body. The main structure of the wing consists of two spars, which are designed to take the flexural loads over their whole length and also loads due to differential bending in the inner portion. Outboard of the gun bay, the wing is of normal stressed skin construction, with two spars and skin reinforced by stringers. The flaps and Frise ailerons are metal-covered.

General Particulars

Principal Dimensions.—(Aeroplane in flying attitude unless otherwise stated, i.e., datum line horizontal and parallel to thrust line.) Span, 41 ft. 7 in.; length overall, 31 ft. 11 in.; *height overall, 14 ft. 7 in.; *height overall, tail down, 15 ft. 3½ in.

*One blade of airscrew vertical and upwards.

Undercarriage.—Type, retractable cantilever; track, 13 ft. 6½ in.

Tail-wheel Unit.—Type, retractable.

Propeller.—Type, De Havilland hydromatic.

Weights and Performance.—Weight, fully loaded, 11,300 lb.; maximum speed, over 400 m.p.h.

Napier-Sabre Aero Engine

Towards the end of 1935 the Napier Company took an important step in the development of the twin-crankshaft aero engine by the decision to build a 2,000-b.h.p. model. At that time the highest-powered engine of any type which was available to the aircraft constructor was in the 1,000/1,200-b.h.p. class; and many doubted the wisdom of a decision to embark on the development of such a high-powered engine.

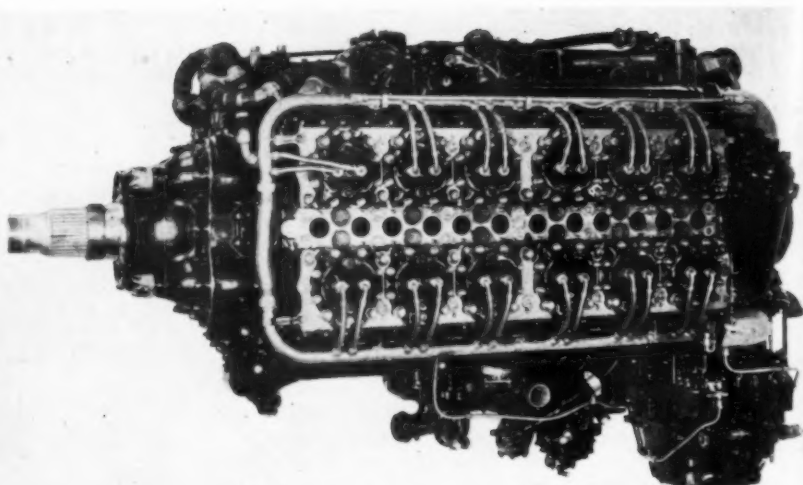
The Sabre is a 24-cylinder, four-stroke, sleeve-valve, liquid-cooled, horizontally opposed "H"-type engine with a two-speed supercharger. The two crankshafts are, therefore, placed one above the other. The pistons, of horizontally opposed pairs of cylinder blocks are coupled to the crankshafts by plain and forked connecting rods. Compound reduction gears transmit the drive from the crankshaft pinions to the helical reduction gear on the propeller shaft. The propeller shaft is on the centre-line of the engine, between the crankshafts, and embodies pressure oil-feed ducts for the constant-speed propeller. The two cylinder blocks are light alloy castings, each comprising 12 cylinders—i.e., in an upper and a lower bank of six cylinders. A hollow shaft, carrying the worm drives for the sleeve cranks, is carried in each cylinder block—between the block and the crankcase. Inside the worm shafts are two flexible shafts to drive the supercharger, which is bolted to the rear end of the crankcase.

The supercharger is of the double-entry type, and the two-speed gear is changed by two hydraulically operated clutches.

Petrol/air mixture is obtained by a four-choke, up-draught carburettor, incorporating automatic altitude and enrichment mixture controls. Automatic boost control is also provided. The mixture from the supercharger is fed to four separate induction manifolds from four supercharger outlets.

The exhaust system comprises six streamline nozzle ejectors on each side of the engine—each ejector serving two exhaust ports. This ejector exhaust system results in an appreciable improvement in aircraft performance, and effective flame-damping is a characteristic of this engine.

The engine auxiliaries and accessories are arranged compactly on the top and bottom covers of the crankcase. The accessories on the upper cover comprise duplex magnetos and distributors, the ignition servo-control unit, the air compressors, hydraulic and vacuum



Side view of Sabre engine, showing arrangement of cylinders.

pumps, and the electric generator. The bottom cover unit includes the oil sump and also houses the shaft and gear train which drive the main oil-pressure pump, the scavenge-oil pumps, coolant pumps and fuel pump.

The engine is started by means of a cartridge starter, housed on the top rear portion of the crankcase. Ignition is provided by two duplex magnetos having separate distributors, and the sleeve-valve arrangement of this engine permits a very neat ignition harness system and provides the maximum of accessibility for the 48 sparking plugs.

Pressure lubrication is, of course, employed; high-pressure oil is fed to the main and big-end bearings and reduction gears, etc., and a secondary or lower pressure system lubricates sleeve drives and accessory drives, etc.

Cooling System

The engine coolant consists of a mixture of water and glycol. The radiator, together with the oil cooler and the air intake, is contained in a low-velocity cowl in a forward position under the engine. The degree of cooling is regulated by a controllable flap at the exit of the cowl.

The header tank is situated around the front part of the engine, behind the front diaphragm. The coolant, after passing through the engine, flows through two pipes, one from each upper cylinder block, into the header tank. The coolant then passes through two thermostats attached to the lower ends of the header tank and, dependent upon its temperature, either to the radiator or through two by-pass pipe-lines, picking up on the corresponding radiator outlet pipes on either side of the engine. The coolant is then returned from the radiator, or radiator by-pass, to the pumps for recirculation through the engine.

The oil cooler is assembled within the coolant radiator and is cylindrical in shape, having a hole through the centre which forms the inlet for the air intake to the engine.

Performance Data of Sabre Engine.—Swept volume, 36·65 litres; maximum r.p.m., 3,700; weight, 2,360 lb., maximum horse-power, 2,200.

Decorative Anodising for Post-War Products

By G. O. Taylor, M.S.E., A.I.P.E., F.Inst.P.I.

Under present conditions aluminium alloy products are usually given a utilitarian finish, but the time may be not far distant when advantage can be taken of the many attractive finishes, in a large range of colours and tones, which are obtainable by anodising, suitable for harmonising or contrasting with any decorative scheme. It is probable that many works are preparing designs of products to be so treated, and this article has been prepared to serve as a guide to designers with a view to the successful production of decorative finishes by the anodic oxidation process.

MANY firms at present engaged in the production of light alloy components for the aircraft industry possess anodic oxidation plants in which the parts are processed for protection against corrosion. Under post-war conditions some of these firms skilled in the manipulation of light metals will undoubtedly pursue their arts in furthering civilian uses of aluminium, and in many applications recourse will be made to the anodising process as a means of producing decorative, as distinct from utilitarian, finishes. In considering the production of aluminium or aluminium alloy articles ultimately to be marketed with plain or coloured anodic finishes, much of the responsibility for successful and economical finishing will reside in the attention to certain details on the part of the designer. In fact, production success or failure is largely decided at the drawing-board.

For example, a bowl-shaped article may be provided with a beaded edge to confer rigidity on thin-gauge sheet. But in ensuring rigidity by this means the work of the finishing department is rendered more difficult since it is necessary to prolong unduly the washing period after anodising completely to remove entrapped electrolyte from the beading, so that it cannot subsequently exude to cause staining, corrosion, or bleaching of a dyed surface.

The purpose of this article is, therefore, to discuss details contributing to the successful production of decorative finishes by the anodic oxidation process.

Surface Treatment

Articles to be provided with a decorative anodic finish usually require pre-treatment to eliminate surface scratches introduced during fabrication, or to remove working marks, such as may be introduced, for instance, in a spinning operation. Surface preparation may comprise the use of one or more methods, such as fine shot- or sand-blasting, controlled etching, electrolytic brightening or hand or automatic machine polishing.

Preparation by blasting, etching or electrolytic brightening is of specific rather than general application, and the use of hand or automatic polishing is practised to a greater extent than any other method. It is a curious anomaly, however, that despite the extent to which the polishing process is applied it is rarely considered as a factor in design. On the drawing board great attention is paid to details affecting the economics of fabrication, but beyond perhaps passing consideration

little thought is expended on the equally important economics of finishing. This is unfortunate, inasmuch as polishing and buffing costs are a major item in production charges, and due consideration given to this aspect by the designer can often effect considerable reductions in labour and materials expended in preparing an article for subsequent operations. It may, for example, be possible by a minor modification in shape, to arrange for automatic machine polishing instead of hand polishing, and in any application where mass production may be contemplated this is a factor of prime importance.

As a production operation the art of polishing has not, in general, kept pace with improvements in other mechanical operations, and the means of achieving a polished finish have changed relatively little since the beginning of the century. Preliminary grinding is still carried out with various grades of emery grains glued to the surface of a compressed felt "bob," and the final smoothing or "colouring" with fine abrasive admixed with wax or grease ("compo") applied to the face of a cloth "mop."

Considering first the preliminary grinding or "bobbing" operation, it will be readily appreciated that the amount of useful work that can be carried out by the emery grains glued to the surface is dependent on how long such grains can adhere to the "bob." The longer the grains adhere the more work can be treated before it is necessary for the operative to set the "bob" aside for a new emery coating.

The felt bob is a rigid tool that cannot readily adapt itself to changes in contour on the work surface. Any sharp corner on the article to be ground projecting into the face of the bob will therefore rapidly tear the grains from the surface and the life of the tool will be short.

From the point of view of the time taken to carry out an operation, a "bob" cannot be made to "climb over" a surface projection, and must work round it, which involves changing the direction of grinding several times.

Grinding or "bobbing" operations are more frequently necessary on castings than on wrought products where the smooth surface often enables this stage of preparation to be dispensed with, and polishing or "buffing" with a cloth mop and grease-abrasive composition to be carried out as the first step. The polishing mop or buff is rather more flexible than the felt bob, and will work

more easily into sharp corners without damage to the tool, but from the point of view of economics, the difficulties introduced by surface projections, sudden changes of contour, and sharp recesses remain much the same where "mopping" may be the only operation required to produce a polished surface.

Obviously, where both grinding and mopping are necessary, as in the case of castings or forgings, attention to such points in the design stage can effect considerable reduction in polishing costs. Unless cases of specific products are considered, it is not possible other than to generalise on design points that will reduce polishing costs, but observation of the general principles outlined will enable many pitfalls to be avoided.

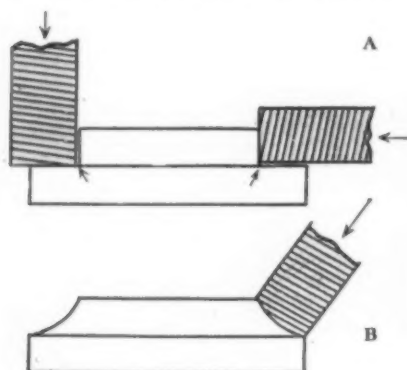


Fig. 1.

General Principles

Wherever possible, corners and recesses should be liberally radiused. This may not always be permissible where a corner or recess has a functional reason, but in cases where there is no functional application attention to detail at these points is amply repaid.

Let us consider, by way of illustration, the case of a circular pedestal base as in Fig. 1A, which might be made either by casting or pressing or spinning from sheet. If only a small radius is given at the corners indicated by arrows, it is necessary to change the direction of grinding or polishing with a normal bob or mop to traverse horizontal and vertical surfaces as shown. Even then it will be difficult to "clean" into the corner with a bob as the emery grains will tend to wear off more quickly at this point.

Provision of a generous radius as at Fig. 1B enables the use of contoured bobs or mops, by means of which both "horizontal" and "vertical" surfaces can be traversed in one operation. Polishing time and tool wear would be materially less for design B than for design A. This is a typical case where design for the use of contoured tools can be applied with advantage and there are many similar instances.

Recesses afford a similar opportunity for reducing polishing costs and effecting a clean job in one operation instead of several. Consider, for example, the case of the recessed pressing illustrated in Fig. 2A. Assuming that it is desired to polish the exterior surface, then design 2B will be capable of quicker handling than 2A. In A the bottom of the recess is substantially flat and is radiused into more or less vertical sides. The bottom, sides and corners could only be partially finished on the polishing lathe, and it would be necessary to recourse

to the use of a flexible tool type machine with miniature wheels to complete the work. If, however, it is possible to form the bottom of the recess as at B as a portion of the circumference of a circle, then with the use of a tool of identical radius the bottom can be finished in one operation.

If in plan view the recess were rectangular in shape, a normal flat type wheel suitably contoured at the corners would clean up or polish the bottom quickly, but if the sides were retained substantially vertical a separate tool would be needed to finish these with a second operation. But if the sides can be flared out a fully contoured tool can be used and both sides and bottom finished in one operation, since the side thrust from the vertical pressure would suffice to provide the necessary friction. This is illustrated diagrammatically in Figs. 3A and 3B. If the recess is of regular curvilinear

form the inside surfaces can easily be polished by use of a cup mop which can be made contoured to appropriate shape as shown in Fig. 4.

Surface projections as illustrated diagrammatically in Fig. 5A are a fruitful source of production hold-up in the finishing shop. Since the polishing tools are more or less inflexible, they cannot climb over the projection and additionally to difficulties introduced in effecting a cleaning of the corners, where the boss meets the plane surface,

it is necessary to work round it by changing the direction of working on the flat surface. Furthermore, it is necessary to perform a number of small movements on the projection itself. Unless for some functional reason it is essential that a projection should be integral with the base it is preferable to make it as a separate piece, when both base and projection can be polished more efficiently and afterwards pegged or screwed together.

If it is essential that the boss be integral, while it will still be necessary to polish round it to finish the plane surface, time can be saved by making the projection of a shape suited to polishing with a contoured tool, as shown in Fig. 5B.

To summarise, hand-polishing is essentially a major item in finishing costs, and attention given to the design of corners, projections, recesses, and to changes in contour (which should be gradually blended in for preference) can effect considerable reductions both in labour expended and wear on tools. Where surfaces can be designed for bobbing or mopping with contoured tools advantages can be derived.

Where the quantities of work involved will warrant it, consideration should be given to the possibilities of polishing on an automatic machine. The factors already discussed apply even more rigidly where continuous automatic output is contemplated. The instances where the quantities involved would be likely to warrant the expenditure in jigs, fixtures and machines for this type of work are, however, limited in comparison with the potential applications for which hand-polishing would be used and do not fall within the scope of this article.

It will be appreciated that the design considerations outlined apply only if efficient and economical polishing

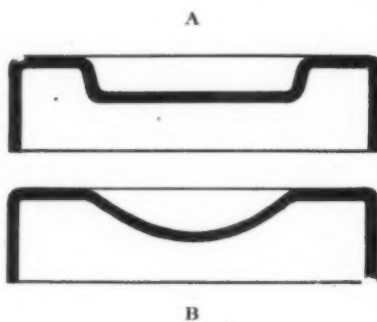


Fig. 2.

is desired as pre-treatment for subsequent anodising. If preparation is to be carried out by abrasive cleaning or etching, the presence of awkward corners or projections or recesses does not particularly affect the economies of the operation, and except in exceptional circumstances neither does it affect successful anodic treatment. There are, however, a number of factors that can affect the success of the anodising treatment, and these will be discussed in some detail since they are all difficulties that can be avoided in the design stage.

Factors that Affect Anodising Treatment

Considering first the case of articles designed to be produced by casting. There are three methods of casting: (a) Sand-casting; (b) gravity die-casting; and (c) pressure die-casting.

Where moderate quantities are involved sand-casting is usually employed, but for a reasonable production, running into hundreds or thousands, where the cost of the necessary dies spread over amounts to only a small

exude to the surface, when the anodic film at the points of porosity will be dissolved off.

This may occur either before or during colouring in a hot dye solution due to expansion effects, but in either case the result will be the same—that is, areas of pin-head size or larger which do not colour, due to weakening or removal of the anodic film and which are conspicuous as white marks against the coloured background. If the work is left uncoloured the visual effects are less marked, but there is potential danger of corrosion due to removal of the film at localised points or to undetected exuded acid. The prevention of such exudation from porous castings is not an easy matter, but some improvement can be derived by swilling quickly after the anodising treatment and then immersing the articles in cold 1% ammonia solution for a few minutes and again swilling.

If, however, the castings are to be anodised by the chromic acid process, it is possible entirely to overcome exudation troubles. Where chromic acid may exude

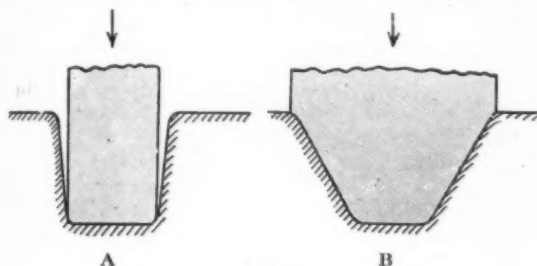


Fig. 3

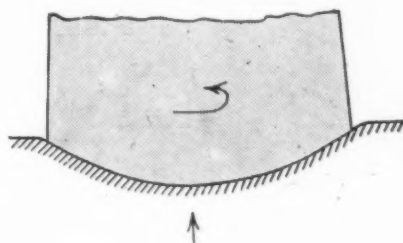


Fig. 4.

fraction of the total production charges for the finished article, production by gravity die-casting offers considerable advantages in closer dimensional tolerances, lower finishing costs, and appearance of the anodised work.

Production by high-pressure die-casting is warranted only where a continuous run of work is possible. Even then it is doubtful whether pressure castings are as suitable as gravity die-castings for decorative anodising as distinct from mere processing to improve resistance to corrosion. Prior to the outbreak of war, very few pressure die-castings could be said to be suitable for decorative anodic treatment due to the presence of surface "swirls" that were difficult to eliminate by polishing, with the result that the anodised metal had a patchy appearance. Whether or not it will be found in post-war practice that this difficulty has been overcome remains to be seen.

Comparing the relative merits of sand- and gravity-die-casting, the advantages are markedly in favour of the die product. Apart from the question of dimensional tolerances, die-castings have a smoother surface and are less prone to porosity. This affects not only polishing costs, but also reduces the possibility of articles being subsequently spoiled by exudation of electrolyte absorbed into the pores of the metal during anodising.

If the use of the sulphuric acid process is contemplated for the decorative finishing of sand- or die-castings, the maximum freedom from porosity in the metal is essential. The acid is absorbed into porosity that may be present under the surface, but communicating with it by what may be almost invisible capillary channels and cannot always be entirely removed in the washing operation following anodising. Residual traces may afterwards

from the metal the anodic film is stained to a brown colour, but is not otherwise affected, since the acid does not attack it. In this case exudation can be overcome either by thoroughly swilling the anodised castings and then leaving them to dry for 24 hours, when chromic acid that has exuded and stained the film can be removed by immersing the parts for a few seconds in cold 50% nitric acid solution, followed by rinsing; or the articles, following anodising and washing, may be soaked for 24 hours in a cold 3% solution of glacial acetic acid followed by rinsing.

If the castings are to be left as anodised, they may then be dried and greased, or if a coloured finish is desired dyeing in a hot dyestuff solution can be carried out in the normal manner.

The alloy from which the castings are to be made is of importance in decorative anodising. Casting alloys containing from 5% to 13% silicon yield self-coloured anodic films varying from blue-grey to slate blue in colour, when anodised by either sulphuric acid or chromic acid processes, and the finish is somewhat dull. They are not, therefore, suited to dyeing except in dark shades, such as blue or black, and even in such dark colours the effect cannot be described as attractive.

For decorative anodising by the chromic acid process the alloy may not contain more than about 5% of copper, which rather restricts the range of alloys that can be used. Typical alloys that anodise to a dove-grey shade satisfactory for dyeing in a wide range of colours are L5, RR 50, DTD 424, and aluminium-magnesium alloys containing up to 7% magnesium with minor alloying elements.

Alloys containing up to 12% copper can be satisfactorily treated by the sulphuric acid process, hence the available range of alloys is more extended than where treatment in chromic acid may be contemplated. In addition to the alloys mentioned under the chromic acid method, satisfactory results can be obtained also with Y alloy, L8, L11 and similar materials, although in general the best results are given with the lower copper alloys, such as RR50 and with the aluminium-magnesium alloys.

Cast-in bushes, studs or the like in metals other than aluminium alloy should be avoided at the design stage, since, unless they can be completely masked with a wax or similar substance during the anodic treatment, they are likely to become corroded. Masking of inserts is a troublesome operation, particularly in decorative work, and is rarely completely successful.

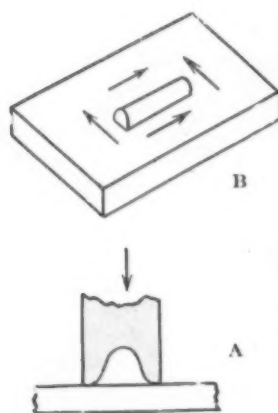


Fig. 5.

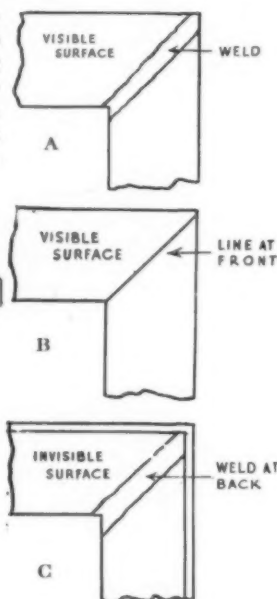


Fig. 6.

ful. Such inserts should, therefore, be made separately and fitted at the conclusion of anodising and auxiliary operations, such as dyeing and sealing.

Passing now to consideration of articles made from the wrought forms of aluminium alloys. In general, all of the wrought alloys can be anodised successfully by either the chromic or sulphuric acid processes, and the choice of alloy will be dependent on the application contemplated. In producing spun shapes from thin sheet, a beaded edge is sometimes introduced to give rigidity. Such a beaded edge, if it is essential, should not be closed right over, otherwise electrolyte percolates into the space inside the beading during anodising and is difficult subsequently to remove. Sufficient gap should be left in the beading to enable trapped acid to run out and be washed away during swilling after anodic treatment. For the same reason, care must also be exercised where folded seamed joints may be contemplated, and in decorative work they should be avoided if other means can be employed.

Joining by riveting is rarely necessary in decorative applications, but where it is used particular attention must be given to the rinsing operation to ensure removal of electrolyte that may have percolated into the lap. Oxy-acetylene welding is often used as a means of

joining, as, for instance, in the case of frameworks, built up from extruded sections. Provided that certain precautions are observed such joints are not unduly detrimental in the production of a decorative finish.

First, it is essential that the welding rod used should be of the same composition as the parts to be joined. If dissimilar alloy is used the deposited metal will anodise to a different colour than the main members, and the area of jointing will be plainly discernible even after colouring. It will also be appreciated that even if a filler rod of the same composition is used, since the deposited metal has a "cast" structure, it will be etched slightly during anodic treatment to exhibit a crystalline appearance that will be absent on the wrought metal. On the visible surface, therefore, the narrower the area of deposited metal the more inconspicuous will be the joint.

It is often possible with frame sections to carry out the welding from the back or "invisible" surface, so that penetration of deposited metal can be stopped just short of the visible surface to give the effect of a thin line scored in the metal. There is then no evidence of welding on the visible surface.

Comparison of the two methods is illustrated in Figs. 6A, B, and C. Whichever method is used maximum freedom from weld porosity and flux inclusions should be sought, and adequate attention should be given to flux removal and dressing of the weld to produce a smooth surface. Where it can be applied hammering of the weld is beneficial in assisting to break up the "cast" structure to render it less conspicuous after anodic treatment.

Butt joints, produced with aluminium solders, while not possessing the mechanical strength of welded joints, can often be used where strength is not an important factor and a thin "scored" line at the point of juncture is preferred. If care is exercised to see that all traces of solder are removed from the surface of the metal either side of the butt joint, such joints can be successfully anodised in the chromic acid bath.

The electrolyte reacts slightly with the thin edge of solder presented at the face and dissolves it away to the extent of about $\frac{1}{32}$ in. below the surface of the metal either side, without otherwise detracting from the properties of the joint. The final effect is then of a black scored line at the juncture. This method is, however, only safe to use with butt joints, where a thin edge of solder is presented to the electrolyte. Fillet joints with relatively large masses of solder available to react with the acid are likely to be unduly weakened.

In general, in designing decorative products to be fabricated from wrought materials, the safest plan, wherever it can be applied, is to allow for jointing after anodising, by means, preferably, of light alloy nuts and bolts or metal-thread screws, which, when finished separately in the same manner as the component parts, are not conspicuous in the finished assembly. If for strength reasons it is necessary to employ studs, screws or the like in other metals, they must be detached while the components are being anodised.

The fact that it is possible to produce ductile anodised and coloured coatings on lengths of strip from which parts may subsequently be blanked and formed without damage to the finish is worth bearing in mind, particularly in the manufacture of small novelties, since obviously considerable saving in production cost will result in comparison with individual treatment of a large number of small parts.

Finally, in considering the future for products decoratively finished by the anodic oxidation process, there is no doubt that this form of finishing, at present commercially applicable only to aluminium and its alloys, will find increasing favour in many directions, and the added sales value that results from the use of colour has been proved in other branches of metal-finishing.

Nowadays, under normal industrial conditions, even

utilitarian articles which a decade ago it would have been considered unnecessary to provide with an attractive finish, must "look good and stay good," and the fact that aluminium products can at relatively low cost be provided with a wear resistant and corrosion resistant finish that can be dyed to a wide range of opaque or translucent shades in single, multi-colour or patterned effects offers a wide scope to the designer of post-war products.

The Heating of Open-Hearth Furnaces with Mixed Coke-Oven and Blast-Furnace Gas

By R. W. Evans, B.Met.

(Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd.)

The theory and practice of mixed-gas operation are discussed, in which is taken into account twenty months' experience of mixed gases in a plant, during which a change-over from 100% producer-gas to 100% mixed-gas has been effected. Provided that the blast-furnace gas can be efficiently and economically used elsewhere, the author is of the opinion that the best method of firing open-hearth furnaces is to use cold coke-oven gas and tar, tar-oil or pitch, particularly where the very high metallurgical loads which have to be carried, require tilting rather than fixed furnaces and where the coke-oven gas is likely to be lean. The author discusses the principles of flame development; the role of the flame; slag foams, their reaction on furnace output and wear; the development of luminosity in coke-oven and blast-furnace gas flames; furnace design; and some metallurgical aspects resulting from the use of mixed gas. The original paper is published by the Iron and Steel Institute; it is reproduced here in a slightly abridged form.*

IN an open-hearth furnace campaign, assuming that the source of heat is not lacking in either quality or quantity, a compromise is always being sought between two conflicting factors:—

1. The rate of production.
2. The life of the furnace.

Generally this means that the rate of production is kept up to the maximum commensurate with a reasonable repair cost and furnace life. If an effort is made to step up production by increasing the gas and air input, the probability is that the furnace life will be considerably reduced, with a very small increase in production, owing to the inability of the furnace to burn in the proper place all the gas delivered to it.

Decreased furnace life upsets regular production, and the schedule of furnace repairs is disturbed. This leads to furnaces being run for longer periods when they are already worn out, or to their having to undergo hasty patched repairs without thorough examination in a desperate effort to maintain production, all of which is only in the nature of postponing the evil day. Therefore, to preserve an even production line, furnace lives must not fall below a certain minimum, and the furnaces cannot be driven at a higher rate than will allow this. Again, if the given furnace life is to be maintained, the average unit production must drop when high metallurgical loads are carried, or when considerable quantities of special or very soft steels are produced, or under any circumstances where long refining times are experienced.

These considerations apply in a greater degree to furnaces using mixed gases than to those working on producer gas. This is due to the greater incidence of

slag forms in mixed-gas operation and the peculiarly accentuated attack of the flame and waste gases on silica brickwork. It is to discuss the theory and practice of mixed-gas operation that this paper has been written. It takes into account 20 months' experience of mixed gases in a plant where, during this period, a change-over from 100%—producer gas to 100% mixed gas working has been effected.

Flame Development

It is both helpful and interesting to note the basic conceptions underlying flame development. The flame in an open-hearth or indeed any furnace is the path occupied by atoms of a combustible gas combining with atoms of oxygen, the chemical combination giving rise to an evolution of heat, which for unit volume of a given gas is constant. The resulting flame temperature, however, depends on various conditions, and primarily on the speed of combustion—i.e., on the rate at which gas atoms collide and combine with oxygen atoms. It also depends on the rate at which the flame loses its heat to the surrounding atmosphere, which, in turn, is a function of the specific heat of the waste gases and the emissivity of the flame. Where large numbers of gas and air atoms combine together quickly in a confined space, the great evolution of heat in the flame cannot be dissipated quickly enough; the result is an intense local build-up of heat, which is revealed as an increase in temperature. Thus, in order to provide the most favourable conditions for high-temperature flames, the first aim is to give the gas and air atoms the greatest facilities for meeting each other. One way of promoting this is to deprive the gas of inert atoms—e.g., nitrogen, which take part in intermolecular collisions without any

* Advance copy. December, 1943.

resulting heat production. This may be done by substituting coke-oven gas for blast-furnace gas—i.e., stepping up the calorific value; another way of reducing the proportion of inert atoms is to use oxygen instead of air, but this is not at present applicable to open-hearth furnaces.

The molecular motion in gases, where the intermolecular attraction is always very small, is definitely "translatory," as opposed to the motion in solids, which is "vibratory"; when a gas is heated the heat energy imparted to it is completely transformed into increased kinetic molecular energy, when the mean velocity of each molecule becomes increased by an increment which is nearly proportional to the increase in temperature above absolute zero ($-273^{\circ}\text{C}.$), at which temperature all molecular motion, translatory and vibratory, completely ceases.

As the molecular velocities increase, so the number of intermolecular collisions rises, and the number of impacts on the wall of a confining medium—i.e., the pressure—is increased. If the gas is free it expands, owing to the outward rush of molecules. This gives the molecules greater searching power and increased probability of collision with oxygen particles; in an open-hearth furnace they have greater searching power and colliding probability owing to their own preheat. The net result is increased speed of combustion, which gives a higher flame temperature.

Finally, given the preheat in air and gas, the only means open to the designer of promoting the rate of molecular collision lies in so designing his ports that the maximum admixture of air and gas molecules is likely to result as soon as possible. This is the aim of the Venturi and the Maerz ports, in which respectively the gas is projected into an intensely directed air stream or the air is directed into the gas stream. The implication is also that the tongue between the gas and air ports should be as thin as is practically possible.

The velocity of gas entry also plays an important part in furnaces of conventional design. High-velocity gas on meeting the air stream produces increased "eddy" effects, leading to greater admixture. High flame temperature as a result of high gas velocity is achieved in the Hoesch furnace.

All attempts at increasing flame temperature, therefore, must be based on increasing the rate at which the gas and carbon atoms collide with oxygen atoms.

The Role of the Flame in Open-hearth Furnaces

Making steel in an open-hearth furnace can be divided into two consecutive stages:—

(1) Melting the charge—a physical process.

(2) Refining the charge—a chemical process.

Practically only one type of flame is available, which has therefore to perform physical as well as chemical functions.

The physical process is relatively a simple one. It consists in imparting the maximum amount of heat from the flame to the charge and the minimum amount to the furnace structure. This is achieved by using the hottest flame attainable and keeping it as near to the charge as possible for the whole of its travel through the furnace. The transfer of heat is effected by both convection and radiation.

In the latter case the heat transferred in B.Th.U.'s per hour is proportional to—

$$(T_f)^4 - (T_s)^4$$

where T_f = absolute temperature of the flame envelope and T_s = absolute temperature of the slag surface.

It is also proportional to the emissivity of the flame envelope; the more luminous the flame the higher will be the emissivity. Hence, for the highest transfer of heat by radiation a hot luminous flame is essential.

In the case of heat transferred by convection from the flame to the charge, if the flame does not touch the charge there will be no heat transfer.

Owing to the high conductivity of steel scrap, the charge is able in the initial stages to absorb considerable quantities of heat, largely by conduction from the flame. The quantity of heat which can be absorbed depends, apart from the flame temperature, on the nature and conductivity of the scrap mass. Ordinary heavy steel scrap is the most efficient heat absorber; light scrap, such as turnings and shearings, possesses too many insulating air spaces; very heavy mill scrap must be thoroughly heated throughout the whole mass before melting takes place, except on the edges and corners. Owing to this considerable withdrawal of heat from the flame, its temperature is lowered, which results in slower melting if the heat input is not stepped up to balance the loss. The furnace heat input therefore should be at a maximum at this stage of the charge: it is probably correct to say that at this period the only limiting factor to the amount of heat that can be delivered to the charge is the ability of the furnace to burn in the proper place all the gas that can be supplied to it.

That melting the charge is performed largely by convection is evidenced by the high rate of melting achieved by a non-luminous coke-oven-gas flame as in the Hoesch furnace; the intrinsic temperature of such a flame is higher actually than that of a luminous flame from producer or mixed gases.

After the addition of hot metal or the melting of cold pig, the chemical process starts along with the completion of the physical process. Reactions commence between the silicon, phosphorus and manganese of the iron and the oxide of iron formed during melting. These reactions are exothermic, so that an additional inside source of heat is provided, which, together with carburisation of the scrap by the carbon of the iron, raises the speed of melting. A point is reached when all the solid material is submerged under the slag, and from this point on the temperature of the charge increases more slowly, owing to the slower conduction of heat through the slag layer and the progressive exhaustion of the silicon, phosphorus and manganese in the hot metal. The temperature of the furnace itself now rises, owing to reflection of heat from the slag surface and decreased absorption, and this high temperature must be maintained in order to drive down the necessary heat for the clear melting of the charge and to make good the increased losses due to radiation. As the melting of the charge nears completion, the flame may be said to have practically fulfilled its active role, and now becomes more passive. The term "more passive" is used because, even during refining, the furnace atmosphere has its own influence on the speed of the reactions. This, however, is not due so much to its temperature as to the effect of the products of combustion on the transfer of oxygen through the slag to the metal.

Given a hot enough flame, melting can be speedily accomplished with or without luminosity, provided that the flame is well down on the charge. With a coke-oven-gas flame the temperature is sufficiently high to melt

fast without any preheat; the flame temperature then depends to a great extent on the air preheat and varies with it. In the case of mixed gases of from 200 to 230 B.th.u. per cub. ft., the flame temperature is not high enough to melt quickly without considerable preheat. It has been observed and commented upon several times by furnace operators that the mixed-gas flame must possess luminosity in order to melt fast. Here the flame melts fast because it is hot, not because it is luminous; the luminosity merely indicates that the preheat has been high, and this, with or without luminosity, produces a hot flame. To maintain this:—

(a) The gas and air preheats should be around 1,200° C.

(b) The gas velocity should be high.

If these two factors are unfulfilled, the melting power of the furnace falls off and production is lowered:

In particular, where the flame temperatures are low owing to inadequate preheat of the air and gas, luminosity becomes a factor of major importance in promoting the transfer of heat. In a recent admirable paper, Fisher,¹ of the Bethlehem Steel Corporation, has shown how the total radiation of the open-hearth flame can be measured and recorded, and, further, has demonstrated that the output of the furnace in tons per hour depends to a very great extent on the flame radiation as measured by him. The above two factors also apply to other heating gases, such as producer gas, but from the point of view of furnace design the problems are easier, because the compromise between ingoing and outgoing port velocities is less important than with the higher calorific mixtures, notably mixed coke-oven and blast-furnace gases.

Refining with a Non-luminous Flame

Refining can be carried out without luminosity, but to a very limited extent only. The Hoesch furnace, without artificial luminosity, will refine fast, but only if care is taken that the charge does not melt out hard.† If it does, and as a result receives heavy feeding, the slag will quickly come up in a foam. The effects of a foaming slag can be disastrous to the brickwork, particularly the roof; once it has started there appears to be very little that can be done to suppress it. The only remedy is immediately to cut down the gas in order to preserve the brickwork, and keep on feeding oxide gently. The charge will, however, gradually lose heat, and the refining time be considerably prolonged, and in addition the furnace will probably be damaged.

The same thing happens, but to a greater extent, when ore is charged and the proportion of iron increased; actually it is impossible to do this with a non-luminous flame, as the resulting foam is uncontrollable.

A non-luminous gas furnace is therefore inflexible, because in order to prevent foaming:

(1) It cannot work with varying proportions of scrap and hot metal.

(2) The charge must be melted out with not more than 0.4-0.5% of carbon and even then it must be treated gently.

(3) Fluorspar, as an aid in fluxing the slag, can be used only sparingly. Bauxite, when available, can be used as a substitute.

The Nature of Slag Foams

The causes and nature of slag foams are not easy to analyse. Foaming slags are always bulky, so that they

rise considerably above the normal slag level in the furnace. In appearance the surface of the slag has a "shimmering" effect, which is caused by the breaking of large numbers of very small bubbles of gas. The surface of the slag also is uneven and gives one the impression that it is not properly liquid. Foaming is accompanied by a slight "sizzling" noise, due to the continual collapse of the bubble skins; this can be clearly heard, and the state of the slag foretold even with all doors down.

The slag in these cases is composed, in the upper layers at least, of large numbers of small bubbles, which are rising slowly to meet the gas, but not through a medium; they are rising bodily, the bubbles touching each other side to side, above and beneath. Why are the bubbles so small compared with those in a normal slag? The probable answer is that even with normal slags the bubbles arising from the slag-metal interface are also small, but in these cases, owing to the considerably lower surface tension of the slag, they quickly coalesce, becoming reduced in number and increased in size; they rise quickly and burst easily, leaving a liquid slag into which the following bubble will rise and burst. As long as it bursts before its successor reaches the surface, a non-foaming slag is the result. Assume for a moment that, owing to high surface tension, the bubble does not burst immediately. The succeeding bubble comes to the surface and lifts the first one clear of the surface before it bursts. If the top one even then does not burst, there may be several bubbles one above the other, all in contact, the whole lot being continually lifted by those underneath. The bubbles cannot be pushed out sideways, because the same thing is happening all over the bath; the result is a foaming slag. If a furrow is cut in the slag—e.g., if the walls of the slag bubbles are forcibly burst by the introduction of a rod, by throwing in scale or by any other addition, the bubbles can then displace themselves sideways into the furrow, and the slag for a short time appears to flow into the furrow. This is a temporary phase only and the foaming is soon resumed.

It is noticeable that as the carbon drops to 0.2-0.3% the foam recedes, the slag resuming its normal character. This may be due to the retardation of bubble formation, so that individual bubbles have time to reach the surface and burst before the arrival of their successors. It is probably due also to decreased surface tension, owing to the changed composition of the slag as the carbon content of the steel drops. Samples of foaming slags show wide variations in composition, though it does appear that foaming is generally associated with high iron or high silica contents of the slag.

Foams such as these are rarely encountered in producer gas-fired furnaces, which can be worked with 100% iron if necessary without serious trouble. It is true that in such cases considerable "swelling" of the charge takes place, owing to the large content of gas bubbles in both the metal and the slag resulting from the intense reactions of the oxide underneath, but the slags are not truly foaming. True foaming will set in during reversal, when the gas is off the furnace for a short period. Also in the case of coke-oven-gas furnaces, provided that atomised tar, oil or pitch to the extent of approximately one-third of the total heat input is injected with the flame, almost any percentage of iron can be carried; in this type of

† That is, with a high-carbon content.

¹ A. J. Fisher. *Iron and Steel Engineer*, 1943, vol. 20, May, p. 61.

² B. S. Ellefson and N. W. Taylor. *Journal of American Ceramic Society*, 1938, vol. 21, p. 205.

furnace, when the charge is on the "ore boil," if all the tar is turned off the slag will quickly rise to a foam. If the tar is reintroduced the flame will cut a large groove through the slag; the high slag on each side of the groove falls into it, and the slag as a whole rapidly flows towards it, so that in a few moments the slag has reverted to its normal state.

Flame luminosity therefore definitely inhibits foaming; whether it is artificially introduced by tar or is naturally present as with producer gas, the effect is the same. The degree of foaming does depend on the degree of "actual" luminosity, because in the case of mixed gases, although a flame may appear to the eye to be dazzling white, yet a foam will result if too much iron is used, which indicates that "actual luminosity" is not the same as "apparent."

Even with producer-gas flames, if the port is so badly worn that that gas is not travelling down on the bath, foaming will be induced, and this applies to a greater degree to mixed gases. The question of flame direction therefore also is important.

Effect of Foaming Slags on Refining

Foaming slags are, by their very nature, excellent insulators. The top surface becomes very hot, and by intense reflection throws the heat back up at the roof, causing it to warm up quickly and melt. Also, owing to decreased absorption of heat by the charge, more heat is thrown on to the outgoing ports and regenerators the temperature of the latter rising steeply. This effect is more pronounced on new than on old roofs, owing probably to the greater conductivity of an old roof. Further, it is not easy to stop the roof "running"; unless the gas is practically all shut off, the running will continue in a lesser degree.

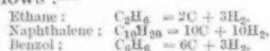
With the gas considerably slackened down, the foam still persists; as a result the steel charge becomes chilled, the slag becomes deficient in iron, and the steel high in phosphorus, both being cold. Further time has to be expended to get heat back into the charge and the slag into condition; the roof has probably been damaged, and in general it is a trying time for furnace personnel, who get impatient and over-anxious to tap.

Luminosity in Mixed Gas Flames

Clean blast-furnace gas burns with a non-luminous flame, as also does normally produced coke-oven gas without preheat. If heated above approximately 900°C., certain changes take place. Methane is decomposed as follows:—

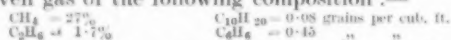


the carbon being released as extremely fine particles, which burn quickly to give rise to luminosity. In addition, the heavy hydrocarbons ethane, naphthalene and benzol contribute their quotas of finely divided carbon, as follows:—



The decomposition of the above gases takes place over the same range of temperature approximately as methane.

In a furnace using, say, 60,000 cub. ft. per hour of coke-oven gas of the following composition:—



the amounts of carbon shown in Table I are yielded on complete decomposition. It will be noted that although

ethane constitutes only 1.7% of the volume of the gas, it yields, by virtue of the greater amount of carbon in its molecule, 11.05% of the total precipitated carbon.

The luminosity of a mixed-gas flame depends entirely on the above constituents, so that variations in particular of the methane and ethane will vitally affect the furnace working.

TABLE I.—CARBON YIELDED ON COMPLETE DECOMPOSITION OF HYDROCARBONS IN COKE-OVEN GAS.

60,000 cub. ft. of gas per hour containing: CH_4 , 27%; C_2H_6 , 1.7%; C_{10}H_8 , 0.08 grains per cub. ft.; C_6H_6 , 0.45 grains per cub. ft.

Constituent.	Total Carbon, Lb. per hour.	Proportion of Carbon from each Source, %.
Methane	541.2	88.26
Ethane	67.8	11.05
Naphthalene	0.586	0.095
Benzol	3.7	0.586
Total	613.28	99.99

There is evidence, noted by Wesemann,³ that the luminosities produced by carbon atoms from different sources are not equal. This appears to depend on the fineness of separation of the carbon, the greatest luminosity being derived from carbon which is precipitated in a very fine state of subdivision. It may be inferred, therefore, that the 613 lb. deposited as shown in Table I will give rise to greater luminosity than that produced by the atomisation of 75 gal. of tar, for instance. In the latter case no atomic precipitation takes place; the tar is merely disrupted by pounding with steam or air into small globules, each probably consisting of thousands of molecules, which is relatively an extremely coarse precipitation.

It appears that the carbon derived from naphthalene and benzol, in particular, gives rise to very high luminosities, which may be due to these more complex molecules breaking down at lower temperatures than methane.

The actual degree of fineness of the carbon derived from these various sources on precipitation is not known, but the carbon in general in a "cracked" coke-oven gas is to a great extent visible to the naked eye, and can be seen deposited on the sides of a glass tube if the hot gas is aspirated through it. This shows that if the carbon is in the first place precipitated in an atomic state, the atoms must soon coagulate into discrete particles which are big enough to be visible in bulk. Rummel and Veh⁴ have shown that when hydrocarbons are cracked by heat, the reaction probably takes place in two stages. At lower temperatures tars and light oils are formed; at higher temperatures carbon skeletons are left, owing to the gradual breaking away of hydrogen atoms. During combustion hydrogen burns first, thus bringing up the carbon aggregates to a white luminosity.

According to Cantelo⁵ the percentage dissociation of methane at various temperatures is as shown in Table II. While a deposition of carbon is shown here as low as 500°C., it is certain that there is no luminosity in the flame in the furnace below 950°C., which indicates that the bulk of the carbon precipitated up to this temperature may be deposited on the regenerator brickwork, so that none, or very little, reaches the flame, or that these

³ F. Wesemann, *Journal of the Iron and Steel Institute*, 1936, No. 11, p. 103 P.

⁴ K. Rummel and P. O. Veh. *Archiv für das Eisenhüttenwesen*, 1911, vol. 14, April, p. 489.

⁵ R. C. Cantelo, *Journal of Physical Chemistry*, 1926, vol. 30, p. 1641.

amounts of carbon are completely consumed by the water-gas reaction (see below).

TABLE II.—DISSOCIATION OF METHANE AT VARIOUS TEMPERATURES.

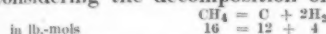
Temperature, °C.	Composition of Equilibrium Mixture.	
	CH ₄ %.	H ₂ %.
500	63.9	36.1
600	37.9	62.1
700	16.3	83.7
750	13.0	87.0
800	7.5	92.5
850	4.5	95.5
900	3.6	96.4
1000	2.0	98.0
1100	0.8	99.2

Simmersbach,⁶ in an older research, has shown that coke-oven gas definitely loses in calorific value as the preheat is increased, as follows:—

Temperature of preheat, °C.	0	800	900	1000	1100	1200
Loss of calorific power, %	—	4	13	18	22	33

This loss he puts down to the decomposition of methane and heavy hydrocarbons; the theory is not explained.

Considering the decomposition of methane:—



if 16 lb. of methane are burnt with oxygen, they produce slightly less heat than do 12 lb. of carbon and 4 lb. of hydrogen, the difference being due to the heat of decomposition of methane. But one volume of methane produces two volumes of hydrogen, so the calorific value per unit volume is considerably lower. This is the result that would be produced by taking samples of the gas before and after preheating and calculating the calorific value per cubic foot from the analysis. In considering an open-hearth system, however, while it is true that the calorific value is reduced per cubic foot, nevertheless the double volume of gas resulting from the decomposition is pushed through the gas port, so that the total heat received by the furnace is the same.

If the theory that carbon is deposited in the checker work and does not reach the port at all is correct, this would account for Simmersbach's statement. In this case, when the furnace is reversed the carbon will burn away in the waste gas, yielding its heat to waste. Quite possibly the degree of fineness of the precipitated carbon would affect the proportions retained by the brickwork and passed on to the flame, which may account for Wesemann's theory that the luminosity of the gas appears to vary with the fineness of subdivision of the precipitated carbon; in other words, if the carbon is deposited coarsely instead of finely, more may cling to the brick surfaces and thus less reach the flame, which then appears less luminous.

Hermanns⁷ goes so far as to say that, owing to this loss of calorific value in coke-oven gas by heating, the regeneration of pure coke-oven gas is out of the question, and that considerable loss of calorific value in early trials of mixed gas operation due to this effect were noted.

This raises the interesting question as to whether the regeneration of a coke-oven/blast-furnace-gas mixture is in fact the most economic and efficient way of utilising the coke-oven gas. An alternative method which suggests itself is to regenerate the blast-furnace gas only in smaller regenerators; the coke-oven gas can be introduced cold through water-cooled burners either at the back of the

gas port, where it would be injected into the hot blast-furnace gas, or direct into the furnace above the gas port. The resulting non-luminous gas could be rendered luminous by the introduction of tar through the coke-oven-gas burner. This method would possess at least the following advantages:—

- (1) The total calorific heat of the coke-oven gas would be delivered to the furnace.
- (2) Losses of coke-oven gas past leaking dampers would be eliminated.
- (3) Thermal losses due to the endothermic nature of the cracking of the hydrocarbons would be eliminated.

One factor which has a great effect on the luminosity of mixed-gas flames is the moisture content of the mixture. This gives rise to the water-gas reaction:



in which the carbon precipitated by dissociation of the hydrocarbons is eliminated by interaction with water vapour. While the carbon is precipitated apparently at 950°–1,150° C., the water-gas reaction reaches its maximum intensity at 1,200°–1,250° C., but proceeds also at lower temperatures.

Table I shows how 613 lb. of carbon per hour are precipitated from the complete dissociation of 60,000 cub. ft. per hour of coke-oven gas. If, in mixed-gas operation, this is mixed with 120,000 cub. ft. per hour of blast-furnace gas, and if, as was determined in an actual test, the coke-oven gas enters the valves at 23° C. and the blast-furnace gas at 18° C., it can be shown that the blast-furnace gas brings in 2,448 cub. ft. of water vapour per hour and the coke-oven gas 1,662 cub. ft., making a total for the mixed gases of 4,110 cub. ft. of water vapour per hour.

Calculations show that the weight of carbon required to combine with the oxygen of 4,110 cub. ft. of water vapour is 84.5 lb., so that the 613 lb. of carbon precipitated in this case is decreased by 84.5 lb. or 13.77%, owing to the presence of these amounts of water vapour. If the blast-furnace gas entered the valve at 40° C., the greater amount of moisture carried would be sufficient completely to eliminate the whole 613 lb. of carbon, the result being complete lack of luminosity. In practice it is unlikely that all the water vapour is decomposed, owing to the temperatures of preheat not being high enough, but there is here the source of a considerable loss of luminosity.

The cure is to cool the gases as far as possible before entry. This is doubly important where the proportion of methane and higher hydrocarbons is already low, and where probably high checker temperatures are carried to extract the "last ounce" of luminosity out of an already lean gas; the furnace reactions are more sensitive to variations with low than with high luminosity.

Another important point is that no water should be allowed to leak on to any part of the culverts or regenerator brickwork. At the average culvert temperature the dew-point of the gas is high, so that large amounts of moisture can be carried in.

Where liquid fuels, such as tar, are used as "carburettors," these reactions suggest that compressed air would be a greater asset than steam as the atomiser.

Mixed Gas Practice and Furnace Design

Normally, mixed gases are regenerated and injected into the furnace through ports of conventional design.

⁶ O. Simmersbach, *Stahl und Eisen*, 1913, vol. 33, p. 239.
⁷ H. Hermanns, "Das moderne Siemens-Martin-Stahlwerk," Halle, 1920; Verlag v. Wilhelm Knapp. English translation: "The Planning, Erection and Operation of Modern Open-Hearth Steel Works," London, 1924. Ernest Benn, Ltd.

Furnaces designed to use producer gas which are converted to use mixed gases must have the gas ports decreased in area if adequate velocity is to be maintained, owing to the use of a 220-230 B.Th.U. gas as opposed to 140-150 B.Th.U. for producer gas. On the suction end, the smaller port has to pass considerably greater volumes of waste gas through in order to warm the checkerwork up to "cracking" point, a temperature normally higher than that required with producer gas, and, it must be borne in mind, with a cold gas entering the regenerator on reversal instead of hot producer gas. All this means that the suction on the gas port must be much higher with mixed gas than with producer gas practice, and this is generally achieved by an auxiliary damper placed in the air return and sometimes by decreasing the air port area as well. With the greater suction on the gas system more air infiltration takes place, a most prolific source of loss of heat efficiency in mixed-gas practice.

The size of the gas port is a key item in the design of mixed gas furnaces. If it is too small, it is impossible to preheat the gases sufficiently, owing to the very great cooling effect on the checkers of the infiltrated air. In such a case the auxiliary damper may be progressively lowered, until a point is reached at which the gas checker temperatures actually decrease, owing to the greater cooling effect of these air leaks; needless to say, at this point the total draught on the furnace decreases and the furnace pressure itself rises.

Also, with a small gas port the pressure in the gas system when "on gas" is so high that large amounts of gas leak through the brickwork crevices, particularly on the uptakes, which is dangerous where blast-furnace gas is concerned; larger amounts also will leak past damper-type valves, an amount that is increased by the higher suction behind them. Further, any advantage which it might be hoped would accrue from the higher ingoing velocity of the gas is lost owing to the lower preheat of the gas. If the gas port is too large, higher preheats can be achieved without high suctions and pressures, and therefore with less leakages. From the thermal efficiency standpoint this is far more desirable, but a low ingoing velocity, with low flame temperature development and rapid wear on the roof is the result.

In an open-hearth furnace the drop in pressure or draught through the flues, checkers, uptakes and ports due to friction with the encountered surfaces is almost negligible compared with the great loss due to the frequent changes in direction of the stream, often greater than a right angle. In order to reduce to a minimum the ultimate or chimney draught required to pull a given volume of waste gas out, the passages and uptakes should, wherever possible, be streamlined, and the changes in direction curved. This will result in less air infiltration and less gas loss.

The regenerators and, if possible, the uptakes should be encased to prevent leaking brickwork, but insulation should be considered with caution. All uptakes should be of ample dimensions.

From the above considerations, straight-through damper-type valves are most desirable, but they undoubtedly leak considerable quantities of gas to the chimney, particularly when the slope is such that the bottom of the damper is nearest to the chimney. If the slope is the other way, gas is liable to leak up through the apertures in the chase through which the stem and water-cooling pipes pass and foul the valve-house

atmosphere. In either case the damper-seat interface must be a machined fit.

It is considered that a water-seal reversing valve of the Forter type would be more satisfactory if used carefully and with proper design, although the "streamline" effects have to be somewhat sacrificed. Nevertheless, leakage to the chimney is completely prevented, so that, if the seal is deep enough, higher draughts can be carried without fear, as also can higher gas pressures.

Port Cooling

Owing to the high exit velocity of the waste gases through the gas port, considerable erosion of the nose of the port takes place. This necessitates water-cooling, of which there are several types in use. The conventional water tubes forming the inside surface of the port have been found effective. If eight 1½ in. pipes are spaced 1 in. apart, a total length of cooling of 19 in. is secured, which is sufficient for most purposes. In this case the inlets are at the front of the furnace, and the water tube runs in, up and over the inside of the gas port and down the other side. The tube is then extended for approximately 9 in. towards the back, where it is doubled back and lies side by side with its ingoing half; the outlet then comes out by the inlet and two cooling pipes are provided from one inlet, four of which would be required for eight cooling pipes. These pipes have the advantage that, as the floor of the air port wears back, fresh refractory cement can be put on the pipes to restore the block contours. The gas port behind the 19 in. of cooling does not tend to widen out, particularly if combustion is not complete in the furnace. To secure cooling of the whole length of the gas port, tank types such as the Blair port can be considered, but here, if the port is long, considerable cooling of the ingoing live gas and of the exit waste gas is to be expected, in spite of the thin brick lining employed in such ports.

Port Velocity and Slope

Owing to the low total mass of solids in mixed gases, it is very necessary that the gas should be injected with a higher velocity than is the case with producer gas; owing also to the low density of the gas, it should be projected into the furnace more steeply. A minimum velocity of 80 ft. per sec. and a port inclination of approximately one in five should be aimed at; the roof of the air port should be more steeply inclined than in the case of producer-gas operation.

A mixture of 60,000 cub. ft. of coke-oven gas and 120,000 cub. ft. per hour of blast-furnace gas heated to 1,100° C. and passed through a port 20 in. × 22 in. will give a velocity of approximately 80 ft. per sec. into the furnace with a mixed gas pressure of about 0.4 in. W.G. If higher velocities than this are sought, while in themselves advantageous, considerably greater leakages are likely to ensue, with resulting losses in thermal efficiency.

As a very rough guide to the flexibility of mixed gas furnaces without artificially produced luminosity, it may be stated that, given the following conditions:—

Heavy hydrocarbons in the gas	1.5-2.0%
Naphthalene plus benzol	0.5 grain per cub. ft.
Maximum temperature of coke-oven gas entering Valves	21° C.
Maximum temperature of blast-furnace gas entering valves	18° C.
Average checker temperature between highest and lowest at reversal	1100° C.
Proportion of blast-furnace to coke-oven gas	2:1
Approximate hot-metal analysis:	
Silicon	0.3-0.4%
Phosphorus	1.2-1.4%
Manganese	1.0-1.2%

the maximum proportions of iron which can conveniently be carried in fixed furnaces with varying percentages of methane in the gas are as follows:—

Methane, %	26-28	28-30	30-32	Over 32
Max. iron, %	40-50	50-60	60-80	Up to 100

Fixed furnaces which have slagging facilities will carry higher proportions. Also where all-cold charges are worked slightly higher proportions can be used. Grey and "kishy" iron will reduce the proportion, whilst low-silicon irons will increase it. With very low water-vapour content and high checker temperatures the proportion may be increased by 10%. Higher naphthalene and benzol contents in the gas will also increase it. Nevertheless, if, owing to variation in scrap or metal quality, the charge melts cut hard and has to be heavily fed, even with the above limits of hot metal bad forming is likely to start, so that for safety's sake the amounts used are usually lower than the above maxima. In all cases it is assumed that the flame is well down on the bath and that complete combustion takes place.

In order to overcome the need of attaining the high gas-checker temperatures, with consequent port erosion, air infiltration and gas leakage, required to obtain luminosity, it is strongly recommended that in all mixed gas furnaces a second source of luminosity be provided.

Artificial Luminosity

The introduction of tar or pitch, atomised by steam or compressed air, will provide artificial luminosity. It can be used in several ways; in most cases it is atomised with steam and delivered to the furnace through a water-cooled "gun." This may be introduced at the back of the gas port where the tar is injected directly into the gas mixture on its way to the mouth of the port. This ensures good admixture, but has the disadvantage that the atomised stream is out of sight, also that difficulties are involved when it is necessary to scrape the floor of the port from the back. To get over this difficulty, the gun has been introduced through the side of the gas port, the jet then turning through a right angle to face the port opening. Here, again, the tar jet cannot be seen.

Another method which has given great promise is to lay a longer gun down the floor of the air port, so that the nose reaches to the entrance of the gas port but is slightly above it. The tar stream then has the advantage of burning in pure preheated air and of being projected well down on the bath, through and in admixture with the gas stream. On occasions when the gas supply has failed, charges have been melted, refined and tapped with tar alone, injected in this manner.

The tar should be heated to 80°-90° C. and arrive at the injector at not less than 40 lb. per sq. in. pressure. The steam used should be dry and at approximately 80-90 lb. per sq. in. pressure: figures for temperature and pressure vary according to the type of gun used. Also, the tar should be cleaned in some sort of strainer before being pumped round the plant. When it is desired to restrict the quantity delivered to any furnace, it is preferable to slow down the pump and thus reduce the pressure, rather than to rely on closing valves, which, unless of special construction, tend to become clogged up in the very small apertures used, so that the flow will suddenly cease.

Most efficient atomisation is probably achieved by pressure alone, but the difficulties of using a water-cooled pressure atomiser with mixed gases are considerable.

Air Requirements

It is of the utmost importance that plenty of air is delivered to the furnace. Even if air is blown and measured in quantity, constant check analyses should be done on the waste gases, which should contain approximately 4% of oxygen. The sample of waste gas should be taken well inside the gas port, so as to avoid interference from air infiltration. If unburnt gases are allowed to reach the exhaust end, rapid wear of the ports, back stoppings and uptakes will take place. Blown air has particular advantages towards the end of a campaign, when the air checkerwork is becoming clogged. With clean checkers of normal aperture the air naturally induced should be quite sufficient.

While exact regenerator dimensions for use with mixed gases cannot be laid down, it can be stated that the drop on reversal in the gas and air checker temperatures should not exceed 200° C. If the range is greater than this, larger checker volume is required; this should be provided by an increase in height rather than in width or length.

Furnace Structure

Sloping back walls, apart from their usual advantages, have been noticed to benefit the roof life: in a shop which has furnaces with straight and sloping back walls, the latter have given considerably greater roof lives, owing, it is thought, to the heat intensity of the flame being spread over a greater area.

It is considered most important that the roof should not be too low over the bath. With correct gas-port design, a roof which has given a good life on producer gas should give a good, if slightly shorter life, on mixed gases. This is attributed to the difficulty of preserving the flame direction throughout its travel over the bath, owing to the greater buoyancy and to the effect of hydrogen and moisture on the silica, though some silica bricks stand up better to this condition than others. The greater tendency to foaming has a bearing also on roof wear. The lower the roof over the bath the faster the furnace will work and the lower will be the heat consumption, but the risks are great, and short lives may be the result.

Mixed Gas Operation

The operation of mixed gas furnaces depends to a far greater extent on instruments than is the case with producer-gas furnaces. Normally, in the latter case the instrument panel will consist of:—

- (1) Draught indicator and recorder.
- (2) Air flow indicator (if blown air is used).
- (3) Gas pressure recorder between valves and regenerators.
- (4) Possibly air checker temperature recorders.

In the case of mixed gases, with injected tar, the panel will contain the following:—

- (1) Draught indicator and recorder.
- (2) Blast-furnace gas pressure indicator.
- (3) Blast-furnace gas flow indicator and recorder.
- (4) Coke-oven gas pressure indicator.
- (5) Coke-oven gas flow indicator and recorder.
- (6) Air flow indicator.
- (7) Temperature recorders on both gas checkers.
- (8) Temperature recorders on both air checkers.
- (9) Tar temperature recorder.
- (10) Tar pressure recorder.
- (11) Tar flow recorder.

- (12) Steam atomisation pressure.
- (13) Mixed-gas pressure indicator.
- (14) Furnace pressure indicator and recorder.

It is evident, therefore, that a melter who has spent his life on producer-gas furnaces has considerably to increase the scope of his knowledge when introduced to mixed gases.

Furnaces are normally worked by setting the blast-furnace gas at a constant value and varying the heat input by altering the flow of the coke-oven gas. In a plant working without blast-furnace gas-holders, the blast-furnace gas flow is likely to vary considerably with the pressure, this being dependent on the number of blast-furnaces in operation. This variation affects the process to an extent not generally recognised, as the blast-furnace gas determines the velocity of the ingoing gases. If the flow is set at 120,000 cub. ft. per hour and then varies from 90,000 to 150,000 cub. ft., depending on the gas-main pressure, the variations in calorific input, flame velocity, temperature and direction are pronounced. Likewise, variations in the coke-oven gas pressure are even more disturbing; instances have been noted of a first-hand setting his coke-oven gas flow at 50,000 cub. ft. per hour, which the furnace could well stand; he then goes off with his colleagues to help fettle another furnace and as soon as his back is turned the main pressure increases, his coke-oven gas flow rises to 70,000 cub. ft. per hour, and he returns to find part of the roof a mass of "iceles."

With regard to items (7) and (8) above, the radiation pyrometers should be sighted on to the top of the checkerwork adjacent to the bridge. In this connection it may be mentioned that the same air and gas preheats have been found with widely differing regenerator capacities, which, it has recently been pointed out, are due to the considerable regenerative potentials of the slag pockets and uptakes.

Items Nos. (9) to (12) govern the correct atomisation of tar, and are important where the tar gun is out of sight. No. (13) will give very good indications, when a furnace becomes sluggish, of where the trouble lies.

No. (14) is considered to be of the utmost value, particularly in plants where the chimney damper or boiler fan are easy and handy to manipulate. If intelligently used it will pay large dividends. A suction in the furnace—with consequent air intake through the doors, its effect on flame direction and on the checker temperatures, and also the implication that the gas or air delivery is insufficient—is as prolific a cause of loss of production as a comparatively high pressure, with consequent general wear on the furnace and implications that the checkers are obstructed or the valves are not operating properly. The furnace should work best with a pressure of approximately +2 mm. W.G., and the draught conditions should be adjusted to give this. Finally, a calorimeter such as the "Sigma" and temperature indicators in the blast-furnace and coke-oven gas mains entering the shop are considered indispensable.

Mixed Gases and Dolomite Consumption

Experience has shown that dolomite consumption is lower with mixed gases than it is with producer-gas practice, and on an average less bottom trouble is experienced.

On one furnace which had a new bottom installed at the time of conversion to mixed gas, notes of fettling times and dolomite consumptions were kept for a nine-week period after the furnace had worked 27 weeks.

For this nine weeks the average fettling time was 39 min. per charge, including all "bad-bottom" time; the dolomite consumption was 51.5 lb. per ton of ingots; the roof life incidentally was 36 weeks, without any patching.

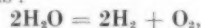
It pays to use finer grades of dolomite or tarred dolomite for topping the banks, because, if foams are experienced, strength is needed at the sill levels. It has been found that the bottom tends to build up in the shape of a promontory in front of the gas port, and the difficulty often is to keep the bottom down to correct levels rather than to fettle it. In general, bank erosion is about the same for mixed gas and producer-gas practice, but the bottom requires less dolomite in the former case.

Metallurgical Considerations

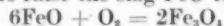
It is found that mixed gases without tar addition appear to have a less oxidising effect on the bath than producer gas, even though there may be the same percentage of oxygen in the waste gases in both cases. For instance, mixed gas furnaces run on a lower proportion of iron in the charge; an 80-ton charge will take, say, 24 tons of iron without charging oxide, while with an exactly similar charge a producer-gas-fired furnace will take 30–32 tons to melt out at the same carbon content. Also it is found that the percentage loss of manganese after the ferro-manganese addition to the bath is, on an average, less with mixed gases, so that less ferro-manganese is required to bring up the bath manganese to the desired point.

Further, it has been noted that slag-metal equilibrium is reached more quickly under a mixed gas flame, so that it is possible to run the carbon very low with less iron (total) in the slag. A heavy addition of scale to the charge will run the carbon down rapidly, but as soon as the feed is exhausted the bath appears to reach a dead-melted condition quickly, even at low carbon contents; this necessitates greater care to prevent rephosphorisation, to which there is a distinctly greater tendency than in producer-fired furnaces.

All this is probably due to the higher percentage of hydrogen or of water vapour in the furnace atmosphere. If at the highest temperature of the flame water vapour is dissociated thus:



it is possible that the oxygen would show itself as free oxygen when the waste gas was analysed, in which case combustion in the furnace would be judged complete, though at the same time free hydrogen was playing over the bath; free hydrogen will also be present from unburnt particles of the gas. At the face of the slag, where temperatures are considerably lower than at the highest temperature parts of the flame, hydrogen may be able to recombine with oxygen and thus seize it before it is able to raise the slag FeO to Fe_3O_4 —i.e.,



In this way the transference of oxygen through the slag to the bath is inhibited. Thus, oxidation oxygen has to be added more as oxide rather than as derived from the furnace oxidising atmosphere, and even after scale additions the oxidising effect appears to be more quickly neutralised, probably owing to the reducing effect of hydrogen. It is due to this that brisk boils are observed on mixed gas baths only while oxide is working in the slag; when this is exhausted, the boil subsides and the slag looks stiffer, which is sometimes attributed to a "thickness" due to excess of lime.

Ferrous oxide in the slag may accumulate as oxide is added, the added Fe_3O_4 giving up to hydrogen one atom of oxygen to become ferrous oxide, which is not further reduced, but also is not further oxidised as shown above. In this way the slag may have a reasonably high total iron which all exists as non-reactive ferrous oxide.

In a producer-gas furnace the slag's store of oxygen is constantly being replenished by the conversion of FeO to Fe_3O_4 at the slag surface and in consequence possesses a quantity of total iron which is capable of exerting an oxidising effect at the slag-metal interface.

It is on account of this quick attainment of equilibrium that rephosphorisation has to be so carefully guarded against.

With very open slags, such as those low in lime, the oxidising and reducing reactions have far more scope to operate, owing to the greater freedom of the slags. Thus, when the carbon is dropping fast under an open slag which is freely boiling, lime is added to steady up the bath; this checks the transfer of oxygen through the slag by slowing up the rate of presentation of FeO molecules to the surface of the slag for more oxygen. In this case whenever FeO particles do appear at the surface they are converted into oxygen carriers to the steel beneath; Fe_3O_4 molecules are unaffected.

Under mixed gases, however, the effect of increased lime is to prevent the Fe_3O_4 molecules from appearing at the slag surface so often, and thus being reduced back to FeO :



In other words, under mixed gases it is not much good adding large quantities of oxide to a thin slag, owing to the probable high rate of Fe_3O_4 reduction and loss of effective oxide at the slag surface.

Conclusion

The conversion of a producer-gas-fired furnace plant to mixed gas firing or to firing with cold coke-oven gas plus tar is generally carried out at the same time as increased quantities of coke-oven gas and clean blast-furnace gas are made available. If the coke-oven gas

is rich in methane and heavy hydrocarbons, the regeneration of a blast-furnace/coke-oven-gas mixture is as efficient and economic, so far as steelmaking is concerned, as any other method of firing. Where, however, the coke-oven gas is lean, containing less than 27% of methane with a normal heavy hydrocarbon content, tar must be used as an artificial illuminant. The difficulties of efficiently introducing tar with mixed gases are considerably greater than when cold coke-oven gas plus tar are used, the difficulties being chiefly concerned in the shape of the gas port, which even in the case of producer-gas operation, is the major factor in determining the life of the furnace. The introduction of a mixture of cold coke-oven gas with tar as an illuminant is effected through a water-cooled burner; the direction of the flame is constant, and there is no worry about the gas-checker temperatures, there being no gas regenerators.

In any plant where the amount of coke-oven and blast-furnace gas available becomes increased and, on the grounds of economy, the scrapping of the producer plant is considered together with the conversion of the open-hearth plant to firing with available gases, the question of the most efficient utilisation of the total gas surplus is one to which the most searching deliberation should be given.

Provided that the blast-furnace gas can be efficiently and economically used in other spheres of heat requirement, the author is of the opinion that the best method of firing open-hearth furnaces is to use cold coke-oven gas and tar, tar oil or pitch, particularly where the very high metallurgical loads which have to be carried require tilting furnaces rather than fixed furnaces and where the coke-oven gas is likely to be of a lean nature.

An open-hearth operator who has confidence in the regularity of his heat input and resulting flame temperature is relieved of at least half of his normal troubles; he can then devote his time to the ultimate duty of every open-hearth manager, that of producing more, better and cheaper steel.

Palladium: Some Properties and Uses

By J. C. Chaston, Ph.D., A.R.S.M.

In a recent issue information was published on the above subject which has probably led to some confusion, and in order to clarify the position the latest available figures are given in this article for the physical properties of palladium. Particular attention is directed to its capacity for dissolving hydrogen and transmitting it by diffusion. Some of the uses of this metal in pure form or as alloys are briefly discussed.*

THE literature dealing with palladium, and indeed with any of the platinum metals, is in many respects vague and contradictory, so that it is not easy, without first-hand experience, to sift the wheat from the chaff. Particularly is this the case if reference is made to the larger chemical dictionaries, where the results of all published investigations from the early days of the nineteenth century until the present time receive mention, whether they be crude qualitative observations or the most carefully conducted experimental studies. Unless care is taken in weighing evidence, and unless the relative standing of the original investiga-

tors can be assessed, a very misleading picture may be obtained of the present state of knowledge.

Palladium is second in abundance to platinum among the platinum metals—platinum, palladium, iridium, rhodium, osmium, and ruthenium. These six metals generally occur together in nature, but the proportion represented by palladium may vary greatly in different deposits. Alluvial deposits of crude platinum contain 0.3–1.8% of palladium,¹ but in the well-known copper-nickel deposits of the Sudbury district of Ontario, Canada, which are the principal sources of palladium,

* 1 "Metals of the Platinum Group." R. H. Atkinson and A. R. Raper, *J. Inst. Met.*, 1936, 59, 179–210.

palladium and platinum occur in approximately the same amounts. Palladium is also found in important quantities as the mineral Braggite (PdPtNi) S, in the sulphide-bearing urite deposits in the Rustenburg district of the Transvaal and as stibio-palladinite, Pd_3Sb (associated with Braggite) at Potgietersrust.

Very little authoritative detailed information is available concerning the methods used for the refining of palladium. The general chemistry of the process has been studied at the United States Bureau of Standards by Wichers, Gilchrist and Swanger, who published a classical paper on "Purification of the Six Platinum Metals" in the American Institute of Mining and Metallurgical Engineers, Technical Publication No. 87, in 1928; and the analytical separation of the metals has been discussed by Gilchrist and Wichers in the *Journal of the American Chemical Society*, 1935, 57, 2565-2573.

Palladium, the lightest metal of the platinum group, is, when pure, very malleable and ductile; it is readily worked to sheet or wire, and it can be beaten out into leaf in the same way as gold. Like all the noble metals, it resists oxidation at normal temperatures, and does not tarnish in ordinary atmospheres. However, like some other noble metals, it is not absolutely immune from oxidation in all conditions. If it is heated to between 400° C. and 800° C. an oxide coating rapidly forms, and the metal is readily attacked at room temperatures by nitric acid, ferric chloride, moist chlorine, bromine, and iodine.

The oxide coating formed when palladium is heated in air differs from most base metal oxides in one important respect. It is stable only within a narrow range of temperature, from about 400° to 800° C. When palladium is heated above 800° C. the tarnish film decomposes, and if the metal is then quenched in water it will remain bright.

The best known and perhaps the most widely studied characteristic of palladium is its capacity for dissolving hydrogen and transmitting it by diffusion. Graham observed in 1867 that when palladium was heated in hydrogen and slowly cooled in the gas it could absorb up to 935 times its volume of hydrogen. Since that time, very many investigators have studied the absorption of hydrogen by palladium and have discussed at length whether definite hydrides are formed, how many hydrides may exist, or whether the hydrogen atoms simply enter the palladium lattice to form solid solutions. The exact mechanism is still a matter of some controversy, and it may be sufficient here to point out the undisputed facts that absorption of hydrogen is accompanied by an expansion of the metal of the order of 0.004% in linear dimensions for each volume of gas absorbed; and that the solubility (unlike that in most other metals) falls rapidly as the temperature is raised (though the rate of diffusion of course increases). The best known use to which these properties have been put is in palladium thimbles, which are sealed into vacuum assemblies for the purpose of admitting very pure hydrogen to the vacuum system; when the thimbles are heated and surrounded by an atmosphere containing hydrogen—even by the simple application of a bare gas flame—hydrogen (and no other gas) diffuses through the metal. The gas-metal reactions need, of course, to be kept in mind when fabricating the metal; and during

melting an additional complication is provided by the very great solubility of oxygen in molten palladium.

TABLE I.—PHYSICAL PROPERTIES OF PALLADIUM.

Atomic number	46.
Atomic weight (1940)	106.7.
Melting point (a)	1,555° C.
Density at 20° C. (b)	11.96 gm./cm. ³
Structure	Face-centred cubic. No allotropic modifications are now considered to exist.
Coefficient of linear thermal expansion (c)	11.67×10^{-6} at 0° C.
Electrical resistivity at 20° C. (b)	10.8 microhms/cm. ³
Temperature coefficient of electrical resistivity (b)	0.00377 (average value, 0–100° C.).
Vickers' hardness, annealed (b)	37 approx.
Ultimate tensile strength, annealed (b)	12 tons/in. ² approx.

(a) See text.

(b) R. F. Vines, "The Platinum Metals and their Alloys," International Nickel Co., 1941.

(c) Holborn and Day, *Ann. Physik.*, 1901, 4, 101.

The physical properties of palladium call for little special mention. The values which are now generally accepted as most reliable are summarised in Table I. The melting-point of palladium is of some special interest, as, falling between the melting-points of gold and platinum, it is widely used as a fixed point in calibrating thermocouples for precision thermometry at high temperatures. Among the most recent determinations are those of Schofield, who, working at the National Physical Laboratory, found in 1936 a value of $1554.4 \pm 1^\circ$ C., and of Fairchild, Hoover and Peters of the United States Bureau of Standards, who in 1929 reported $1553.6 \pm 0.5^\circ$ C. In this country, 1555° C. is the most generally accepted figure, and in America 1554° C. appears to be usually quoted.

Among the relatively few alloys of palladium which have been adequately investigated, those with cobalt, copper, gold, iron, nickel, platinum, rhodium, and silver appear to form unbroken series of solid solutions. Order-disorder transformations occur in the copper-palladium and iron-palladium systems.

Palladium itself is widely used as an alternative to platinum as a contact material in telephone apparatus in the United States, but to a less degree for this purpose in this country. It also finds applications—usually in a finely divided form—as a catalyst for hydrogenation processes. Palladium leaf has been used to a limited extent as a decoration in book-titling and for glass signs.

In alloy form, palladium is an important constituent of many complex gold-base wrought and cast dental alloys, where its resistance to tarnishing is of value. The addition of more than about 15% of palladium to gold destroys the gold colour altogether, and at one time palladium-gold base "white golds" were used for jewellery. Palladium-gold alloys have also been used to a small extent for chemical laboratory ware, and they are useful for heat-fuses of furnaces working at high temperatures. A thermo-couple consisting of 40% gold-palladium alloy coupled with 10% iridium-platinum develops a remarkably high e.m.f. and has useful applications for measuring temperatures up to about 600° C.

The silver-palladium alloys are widely used for electrical contacts as well as for dental purposes, and—to a less extent—for jewellery. The silver-palladium alloys containing more than about 50% of palladium are very nearly entirely resistant to atmospheric corrosion and tarnishing at room temperatures.

2 "The Platinum Metals and their Alloys," R. F. Vines, International Nickel Co., 1941.

A Comparison of Some Properties of Beams in Magnesium and Aluminium Alloys

Some properties of uniform stable cantilever beams in the form of round or square bar, angle or T section, channel, I section or tube in magnesium and aluminium alloys are compared theoretically and in a preliminary way, and the results are presented in graphical form for quick reference. We are indebted to F. A. Hughes and Co., Ltd., for permission to reproduce this data from their October, 1943, issue of "Magnesium Review."

MANY components in aircraft engineering are subjected to bending loads, and of all the different types of material available for aircraft structural work aluminium and magnesium alloys are used in predominant measure. The choice as to which of these materials should be used for a particular part subjected to bending depends largely upon the mechanical properties and weight characteristics. The factors involved in such a choice are usually weight, strength and deflection or stiffness, and the merits of one or the other of the two types of alloys for a particular application are not obvious at first glance.

It is therefore proposed to compare theoretically and in a preliminary way some properties of uniform stable cantilever beams in the form of round or square bar, angle or T section, channel, I section or tube in magnesium and aluminium alloys, and to present the results in graphical form for quick reference.

The method of presenting the comparison data has been derived as follows:—

Three basic criteria are involved—viz., weight, strength and stiffness; a fairly wide range of stresses or stress ratios must be covered, as there are several different alloys in both the magnesium-rich and aluminium-rich ranges. Comparison data are required for the standard types of section, details of which are given in Fig. 1. To cover these requirements, calculations have been made to provide data giving, for the two series of alloys and for all the standard sections:—

- (1) Strength ratios on a basis of equal weight.
- (2) Deflection ratios on a basis of equal weight.
- (3) Weight ratios on a basis of equal strength.
- (4) Deflection ratios on a basis of equal strength.
- (5) Strength ratios on a basis of equal deflection.
- (6) Weight ratios on a basis of equal deflection.

The charts (Figs. 2-5) show the ratios providing the desired comparison to be made for any given ratio of permitted stresses* in aluminium against magnesium from 1.0 to 2.0.

To obtain sections of equal weights, equal strength or equal stiffness it would be possible to vary either or both the external dimensions and the thickness in an arbitrary and irregular manner, but systematic comparison would thereby be rendered difficult or impossible. The method adopted here is, therefore—for all sections except solid

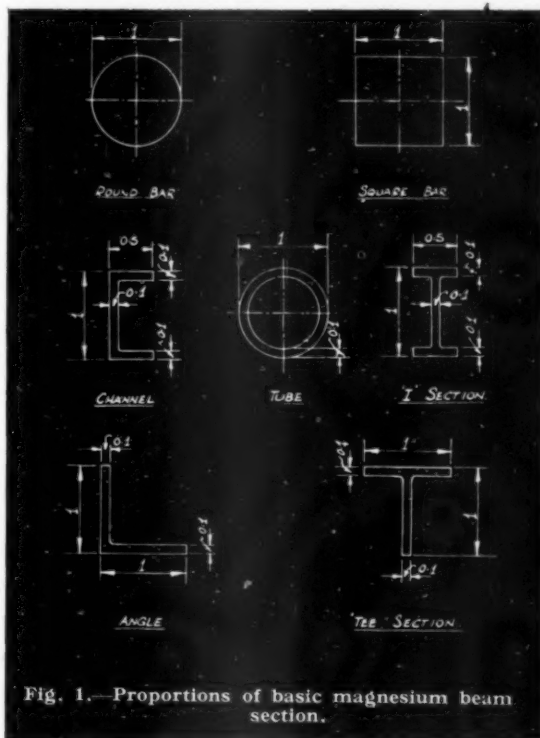


Fig. 1.—Proportions of basic magnesium beam section.

bars—to assume the external dimensions as fixed and alter as necessary the thickness of flange and web equally. With the solid bar sections it is necessary to alter the external dimensions.

Therefore in the following discussion (in all cases except for solid bars), where the comparison is made between magnesium alloy sections and aluminium alloy sections, it is assumed that the external dimensions of the sections are the same for both alloys; the curves are based on this assumption.

The beams will be considered to be loaded within the elastic limits of the materials and the effects of shear stress and secondary failure will be ignored. The latter aspect is often one of great importance, but requires separate discussion. The stress-strain curves of the material will be considered to be straight within the limits of loading—i.e., the stress at any position across

*The term "permitted stress" indicates the maximum working stress of a given type of the given material. Thus, if a component is to be designed on proof stress, the permitted stress is the proof stress of the material concerned; and if the basis of design is fatigue stress, then the permitted stress is the fatigue stress, etc. It is assumed that the same factors of safety apply in the case of both materials.

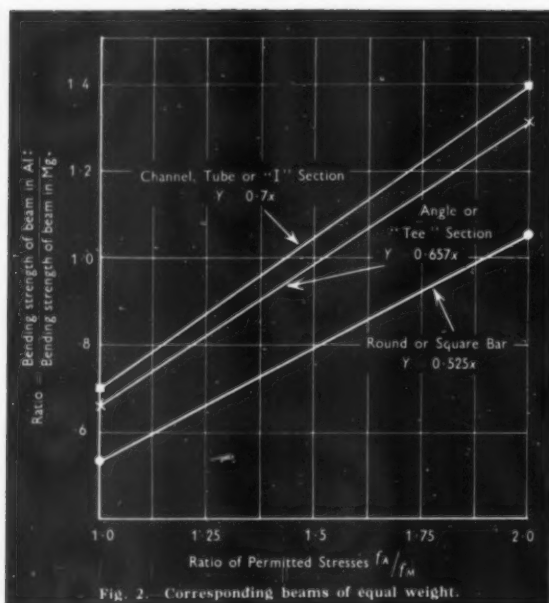


Fig. 2. Corresponding beams of equal weight.

the beam section will be considered to be directly proportional to its distance from the neutral axis. This assumption is strictly justifiable only on the grounds of expediency, since the characteristic stress-strain curve for these materials is not quite straight even at low stress. This characteristic has an effect upon the stress distribution in a beam, slight within the so-called elastic range, but of considerable importance beyond it. Discussion of the feature is, however, outside the scope of this note.

For present purposes the specific gravity of magnesium alloy has been taken as 1.82 and that of aluminium alloy as 2.8. The moduli of elasticity of magnesium and aluminium alloys respectively have been taken as 6.5×10^6 and 10.0×10^6 lb./sq. in.

The properties concerned are calculated from the simple beam formulae—i.e.:

Deflection.— $\frac{WL^3}{KEI}$ or $\frac{C}{EI}$ (i.e., constant external moments assumed).

Strength.—Bending moment $M = fZ$.

Weight.—The weight of the beam refers to the weight per unit length—i.e., sectional area multiplied by the weight of the material per unit volume. The length of the beam is regarded as standard throughout.

Fig. 2 represents the comparative properties of magnesium and aluminium beams, the sections of the latter in each case having been determined as explained above, so that the weights of corresponding beams in magnesium and aluminium are equal. The curves show the ratio bending strength aluminium/bending strength magnesium plotted against the ratio permitted stress aluminium/permitted stress magnesium (f_a/f_m).

Figs. 3 and 4 are drawn on the basis of corresponding beams of equal strengths, and Fig. 5 of equal deflections or stiffness.

The formulae for individual curves are stated on the charts. Curves showing the ratio of deflections (equal weights) and the ratio of weights (equal deflections)

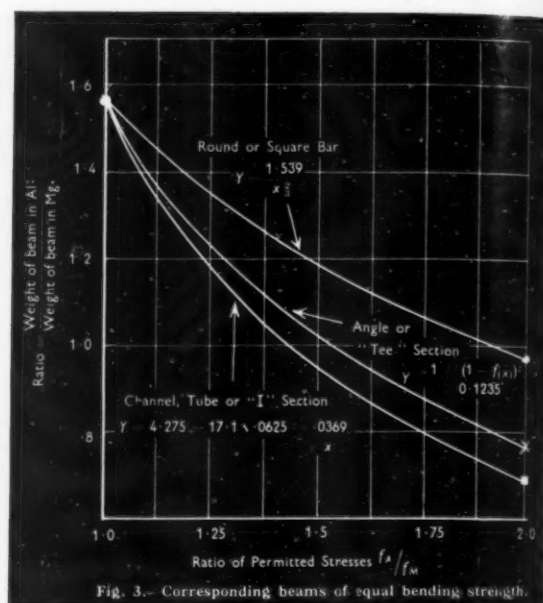


Fig. 3. Corresponding beams of equal bending strength.

cannot be drawn up on a similar basis, since, with equal external moments assumed, the ratios are independent of the ratio of permitted stress f_a/f_m . The ratios—Deflection of beam in aluminium/deflection of beam in magnesium—of corresponding beams of equal weight are therefore constant as follows:—

Round and square bar	1.54
Angle and tee section	0.97
Channel or I section and tube	0.93

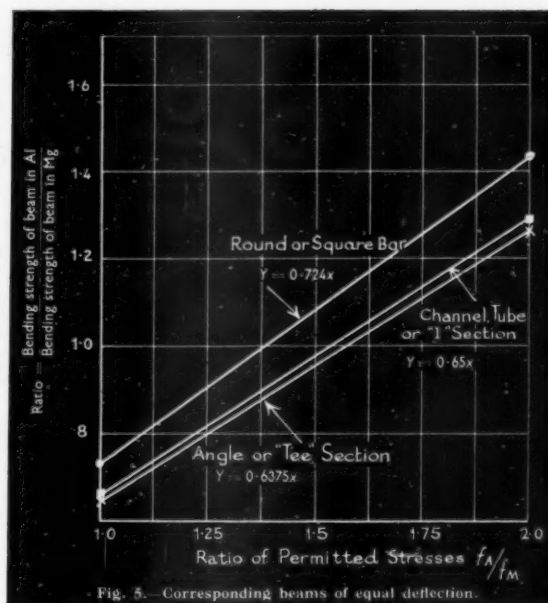
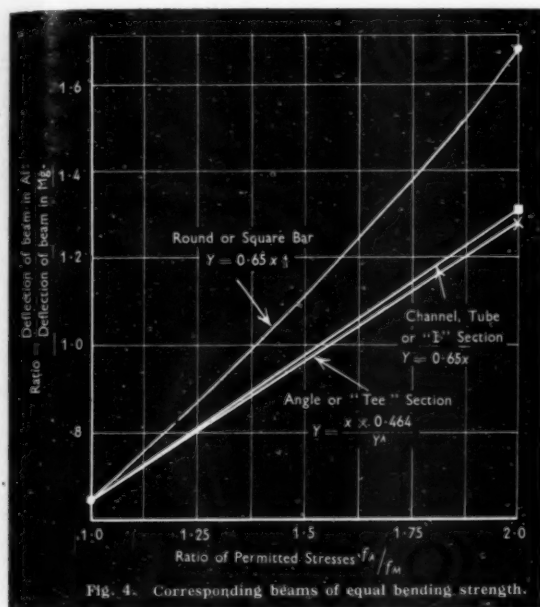
In the case of corresponding beams of equal deflection the ratios—Weight of beam in aluminium/weight of beam in magnesium—are:—

Round and square bar	1.24
Angle and tee section	0.96
Channel, I section and tube	0.92

Interpretation

In using the curves it is advised that their limited application should be appreciated and more information than is justified should not be extracted from them. Except where stated to the contrary in the following analysis, in the case of the shaped sections the curves apply only to sections of the given proportions, but may act as a guide, if used with discrimination, to the properties of similar sections of slightly different proportions. There is, however, no scale effect under the conditions considered—i.e., the dimensional units applied to the various sections are purely arbitrary. The following points of interest arise from examination of the charts (Figs. 2-5):—

In the case of beams of equal weight (Fig. 2) the bending strength of the round or square aluminium beam is less than that of the magnesium beam, where the stress ratio f_a/f_m is less than 1.9. The "shaped" section beams are grouped comparatively closely, but the strength advantage of the magnesium beam is not apparent until the stress ratio f_a/f_m is less than about 1.47. Similarly, when "shaped" section beams of equal strength are compared (Fig. 3), the weight advantage of magnesium is negative for values of f_a/f_m above about 1.47 and positive below this figure, although round and square beams in magnesium show to advantage from a



stress ratio of 1.9 downwards. In general, therefore, where weight and bending strength are considered together the critical permitted stress ratios f_a/f_m lie in the region of 1.9 in the case of round or square beam and 1.47 in the case of the shaped sections—i.e., the permitted stress in magnesium alloy in a round or square beam must be greater than approximately half that in the corresponding aluminium alloy, and in a "shaped" section beam of the type considered more than about 0.7 that in the corresponding aluminium alloy before it can demonstrate a weight or strength advantage over aluminium alloy under the conditions described.

Examination of Fig. 4 shows that if two series of beams, one in magnesium alloy and the other in aluminium alloy, are designed so that the strength of the corresponding beams are equal, the deflections of the magnesium beams will be greater than those of their aluminium counterparts if the permitted stress of the aluminium alloy is less than 1.36 and 1.55, in the case of solid and "shaped" sections respectively, of that of the magnesium alloy. Similarly, Fig. 5 shows that if the corresponding beams in the two series are designed to have equal stiffness, then the bending strength of the magnesium beams will be greater than that of their aluminium counterparts if the permitted strength of the aluminium alloy is less than 1.36 and 1.55, in the case of the solid and "shaped" sections respectively, of that of the magnesium alloy.

It is interesting to note that where corresponding beams of equal strengths are considered (Figs. 3 and 4), as the permitted stress ratio approaches unity, differences in the shapes of the sections considered have a decreasing influence on their comparative weights and deflections, whereas where beams of equal weights (Fig. 2) and equal deflections (Fig. 5) are considered, this tendency is not particularly marked.

The properties of the tube under the conditions described are identical with those of the channel or I section. This only applies, however, when tubes and channels of equal wall thickness are compared, because,

as already indicated, results usually depend upon the basic proportions of sections examined. Exceptions to the latter are the cases of the channel, I section and tube when the ratio of bending strengths (equal deflections) and deflections (equal strengths) are considered. In these instances the results are independent of the moduli of section, being directly proportional only to the ratio of the moduli of elasticity of the two metals.

It will be noted from the different results obtained on the solid and shaped sections that, within the limits of consideration applied here, if external factors dictate the chosen shape and form of a beam, the relative advantage with regard to the properties of weight and strength (Figs. 2 and 3) of constructing it in magnesium increases as the efficiency of the beam as such decreases, the rate of increase being influenced by the f_a/f_m ratio. The reason for this is clear, since only a comparatively small cross-sectional area (the outer fibres) of a beam of inefficient section will be stressed to the maximum permitted stress of the material of which it is made. The remaining area will be stressed to a diminishing degree towards the neutral axis and in this case will be required to take only a comparatively small share of tension or compression stress. Providing it can withstand the nominal stress in this area, therefore, the lighter the material is, the greater will be the local efficiency. This effect operates particularly where the cross-sectional shape of a beam is dictated by the economics of fabricating processes rather than by design requirements.

Space here does not permit development of the theme sketched above, nor a detailed examination of the full implications of the curves developed. It may, however, be worth repeating that the factors taken into consideration in this note do not cover all the conditions operating when beams are subjected to bending, the assumptions being those applied in the simple theory of bending. The curves are thus open to addition and modification by the results of more detailed analysis, but may nevertheless serve as a general guide on the subject.

Heat-Treating Cast Iron

By J. Edmiston

It is not fully appreciated that iron castings can be made to possess properties that render them capable of withstanding a considerable variety of severe service conditions. When properly produced, under controlled conditions, iron castings can be substantially improved and modern high-duty types react to suitable heat-treatment cycles. Some of the factors affecting the heat-treatment of cast iron are discussed.

TO the engineer, cast iron is not usually associated with high physical properties; rather is it regarded as a low-grade constructional material to be used only in cases where its relative cheapness and ease in fabrication renders its employment advantageous. While it is perfectly true that castings manufactured with little or no regard to chemical composition as related to dimensions or subsequent treatment are not generally amenable to attempts at improvement, it is also true that properly controlled castings can be very substantially improved either in the "as-cast" condition or by later processing. By proper control of all the manufacturing stages it is possible to produce castings capable of withstanding a large variety of service conditions, and, moreover, by employing a regular heat-treatment in the course of manufacture, greatly to facilitate production. Indeed, it might almost be said that the leading characteristic of modern high-duty types of iron is the readiness with which it reacts to suitable heat-treatment cycles.

To understand thoroughly the principles upon which the founding and heat-treatment of these irons are based, it is necessary to consider some fundamental facts. These relate to the influence of total carbon, combined carbon, silicon, and the minor, but still important, effects of the other elements commonly found in plain or alloy irons.

Perhaps the most important single factor affecting the heat-treatment of cast iron is the character and amount of combined carbon. From the heat-treater's point of view, this factor decides whether the iron will harden on quenching, whether the quench need be mild or drastic, and as a secondary result, whether the casting will distort or fracture with the quenching treatment given. In fact, it is the amount of combined carbon in cast iron, like steel, which very largely decides the response to be expected from any particular treatment. It is only logical, therefore, when production runs for heat-treatment are contemplated, that close limits should be placed on the combined carbon, just as in the case of steel, and for the same reason. In spite of this resemblance to steel in its sensitiveness to combined carbon, cast iron can never approach steel in ductility. The scope of any heat-treatment is therefore limited to improving the tensile strength, or the hardness and wearing properties of the casting. With this somewhat narrower end in view, the desirable range of combined carbon becomes more restricted. In the field covered by the everyday plain or alloy irons it is generally agreed that the best combination of properties is obtained when the carbon approximates to the eutectoid composition for the particular alloy. In practice, the aim is always to produce a distinctly hypo-eutectoid composition, especially when, as is nearly always the

case, the castings have to be machined and free cementite must therefore be avoided in the interests of tool life. These considerations, then, tie down the desirable limits of combined carbon to a range usually from about 0.5 to 0.8%, with a tendency to the lower end of the range as the alloy content is increased.

For heat-treatment purposes, it is convenient to consider cast iron as a slightly hypo-eutectoid steel containing a considerable amount of carbon in the form of graphite. Since the graphite is dispersed at random throughout the steely mass, it effectively breaks up the continuity of structure and thus accounts for the lack of ductility exhibited by all cast irons. As the graphite tends to coarseness, the material becomes more brittle, and this brittleness persists in spite of any improvement which may be effected in the steel-like portion of the alloy. Consequently, no great improvement in physical properties can be expected as a result of heat-treatment unless the amount and distribution of the graphite is controlled. It would be anticipated, and experience agrees, that as the graphite tended to a nodular form, as opposed to the long flaky type found in uncontrolled iron, its effect on the strength and brittleness of the iron would be reduced. This factor can be controlled in a number of ways, either singly or in combination. Fundamentally, the size of the graphite is a function of the rate of cooling over the freezing range of the alloy. Considering cast iron as a pure iron-carbon alloy (which in fact is very far from being the case), theoretically only one composition, the eutectic alloy, freezes spontaneously. Furthermore, this eutectic alloy, because of the absence of a freezing range, must form the finest graphite, which, being deposited in a solid metal cannot appreciably increase in size as the casting cools. In the pure iron-carbon alloy, the eutectic occurs at 4.3% carbon, but its exact position is influenced by other elements, notably silicon. It will be appreciated, of course, that if a reduction in the quantity of graphite, as well as refinement, can be achieved, even better physical properties could be anticipated. Most high-duty irons are treated with this end in view, rather than aiming at a eutectic composition for graphite control.

Graphite Control

The most successful methods for graphite control in commercial practice aim at reducing the quantity of graphite as well as refining the structure, and such irons are characterised by a low total carbon, seldom exceeding 3.5%, and often substantially less. The lower limits for total carbon (and also graphite) are fairly well defined by considerations of ease in melting and casting, and is usually held at about 2.9%. It is difficult to cast lower carbon iron in the cupola, and because of the higher melting point, the metal lacks fluidity. These low total

carbon irons are readily melted in the cupola with suitable steel and pig charges, and by adjusting the fuel ratio, may be superheated, although the effect of superheating in this way tends to increase carbon absorption. Superheating, however, can be used for grain refinement to produce the nodular graphite desired in high-duty iron. This technique, largely followed in the production of chill and grain rolls, simply consists of oreing down or diluting a suitable base iron to the required carbon content, raising the temperature to about 1,600° C., and tapping after adjustment of the composition with ferro-alloys. Before casting into moulds, however, the metal is cooled off in the ladle to a suitable casting temperature. By superheating, the carbon is taken into solution completely, so that on cooling it is deposited again in a very uniform and finely divided manner.

Obviously, this process, in essence so simple, is fraught with difficulty for small castings, since it is no easy matter to pour light castings from a large ladle. Apart from this, a separately fired furnace of the open-hearth type must be used to reach the high temperature required. In recent years, some progress has been made with acid-lined arc furnaces of relatively small capacity for this type of foundry, with highly successful results, but the process still presents difficulties for the average foundry plant.

One other important method for producing this type of iron must be mentioned, since the means employed are more readily available in the ordinary foundry. This is the "inoculation" process, in which the graphite is induced to precipitate by means of an addition which produces a chemical reaction. The iron as it runs from the cupola is low enough in silicon to produce a white iron on casting and the requisite silicon is introduced in the ladle to precipitate the graphite. In one process, calcium silicide is used as the "inoculant" for a low carbon white iron, the resulting graphite appearing in the desired nodular form.

With the total carbon under control, the combined carbon in the casting depends on the percentage of graphitising element (chiefly silicon) present. The amount will vary in an inverse manner to the mass of the casting. Assuming silicon to be the only graphitiser present, this will be of the order of 1.75 to 2.5% for the majority of small to medium engineering castings, and sulphur, which acts in the opposite direction, should be limited to not more than 0.15% with sufficient manganese (say, eight times the sulphur) to cover the weakening effect of the sulphur. The greater part of this sulphur comes from the fuel used, and so should be under control by the founder. At all events, its presence is deleterious, and should be kept at a minimum.

The question of phosphorus in high-duty iron raises practical differences of opinion. The nature of the casting largely influences the minimum amount to be used, since it confers fluidity to the metal. If the metal is cold, this property is valuable, but the melting methods in a foundry manufacturing controlled iron should be sufficiently good to avoid difficulties in this direction. Nevertheless, an intricate casting may demand the use of some phosphorus in spite of good temperature control, and the question arises as to the limits to be adopted.

It is well known that phosphorus up to about 0.4% strengthens the iron, while beyond this limit the metal becomes progressively embrittled. Even this amount can cause trouble in castings which must be pressure

tight, and it is consequently better to work to lower limits, depending on the use of alloys for extra strength if this is required. For simple pressure tight castings, 0.1% would be a better limit, going perhaps to 0.15 to 0.2% for the more intricate shapes. For hydraulic work, some makers prefer even less than the above limits with simple designs.

With a knowledge of the foregoing basic principles, along with the practical factors involved, it is not a matter of great difficulty to draw up a basic specification for a reliable engineering iron which will fall within the high-duty types. A simple non-alloy iron, depending on the size of the casting and the purpose for which it is intended, might run on the following lines:—

T.C.	C.C.	Si.	S.	P.	Mn.
2.9—	0.6—	1.7—	0.1—	0.1—	0.6—
3.5%	0.8%	2.5%	Max.	0.4%	0.9%

The type of graphite would, of course, be controlled as would also the total carbon, so as to bring the iron within the "high-duty" class. Such an iron, in small section, would harden readily in oil by quenching from 850° C. to give a surface hardness of not less than 400 V.P.N. in sections up to about $\frac{1}{2}$ in. The utility of this type of iron for such applications as small wear-resisting sleeves and bushes need hardly be emphasised, since it is frequently possible to substitute such components for more expensive case-hardened parts with a satisfactory reduction in cost and machining time. A small bush of this type of simple shape could be cast solid and rough machined to shape, leaving enough allowance for final grinding. An oil quench from 850° C., followed by a "stress-relieving" temper at 150° C., would then provide an excellent wearing hard bush, only requiring finish grinding or honing to size. A comparison of this typical manufacturing schedule with a comparable part, pack hardened or carburised, will show at once the advantage possessed by the iron.

Effects of Alloying

In the development of high-duty iron, the effect of alloying with elements such as nickel, chromium and molybdenum has not been overlooked. As would be expected from the behaviour of these elements with steel, important advantages can be secured by their use. Small percentages of chromium, for example, secures a readier response to hardening by quenching, and the same is true of molybdenum. It therefore follows that these two elements are valuable in counteracting the "mass effect" of the larger castings, and can even be used to induce air-hardening properties. Such an effect can be employed for castings which would crack on oil quenching, although this is seldom adopted in production because of the inevitable difficulty in machining. The presence of nickel strengthens the iron, entering into the ferrite as a solid solution. In this way the tensile strength is raised. Nickel also tends to refine the graphite and thus give a denser structure to grey iron, and has been used for this purpose for hydraulic and other pressure castings for a long time.

Taking each of these alloying elements in turn, their effects, as they influence the range of irons at present under consideration, will be noted.

Nickel acts in the same direction as silicon, promoting graphitisation so that in building up an alloy from a suitable base iron, the silicon is proportionately reduced as the nickel is raised, in order to maintain the correct

amount of graphite and combined carbon. Metallurgically, nickel is only about one-third as effective as silicon in this direction, so that the silicon is reduced in the ratio of 1 : 3 of nickel. Chromium and molybdenum are about equal to silicon in the opposite direction—that is, the silicon is raised as the chromium and molybdenum is raised by equal amounts.

From a heat-treatment point of view, nickel up to 2% evens out the differences in hardness between thick and thin sections, while the other two elements mentioned increase the response of the castings. As in steel, the nickel-chrome combination is often preferred for heat-treatment because of the uniformity of the results under the normal conditions of commercial practice. For heat-treatment, the best ratio is approximately 3 of nickel to 1 of chromium. Often about 0.5% molybdenum is also added as an "improver," especially in heavy sections.

Heat Treatment

The practical details of heat-treatment do not differ materially from the procedure followed in the case of steel. It is desirable that the furnaces should be of the muffle type, capable of maintaining an even temperature over all the charge, and that the temperature be controlled and held to close limits by means of pyrometers. This is not the place to enter into details of furnace construction, and the present writer will not do more than point out the risks of cracking involved in uneven heating in the case of castings which, by their nature, must have a very low strength at high temperature. With this danger in mind, the muffle carries the least risk, since there is then no danger of "hot spots" caused by flame impingement on the work. In order to obtain uniform and reproducible results, the actual temperature of the furnace should be as nearly automatically controlled as possible.

Three main types of treatment are given:—(a) Stress relief; (b) hardening; (c) tempering. When castings are taken from the mould they invariably have some stress inherent in them. Depending on the complexity or otherwise of the casting, these stresses may or may not be dangerous from the point of view of cracking. Highly stressed castings, however, may not present a risk from cracking so much as a risk of closely held dimensions altering on machining or some such operation, and for this reason some form of stress relief is given to a great many engineering castings in production. The castings, if left to themselves, would "season" naturally but slowly. Raising the temperature to a moderate extent accelerates the process and allows the rough castings to "move" to a stable condition without risk. The temperature adopted for this operation must not be high enough to damage the physical properties of the material and is commonly in the range 200°–400° C. The higher the temperature, of course, the more effective the treatment. At the higher end of the range, one hour per inch of section is ample heating time. For castings which are to be machined and put into service, this forms the only heat-treatment which need be given, and for the sake of final dimensions and to avoid distortion, should be the first operation before breaking the "skin" of the casting with tools.

The hardening operation follows the procedure adopted for steel, the heating and quenching cycle being regulated by the nature and shape of the casting.

The temperatures used are commonly from about 780° C. to 850° C., and the quenching liquid oil and, much more rarely, water. The thermal shock of the quench induces high stress as well as high hardness, and if the latter is desired, it can be retained by a light temper from 150° C. to 250° C., thus largely removing the locked-up stress. So important is this point from a service point of view that it should never be omitted after hardening.

Higher temperature tempering corresponds to the sorbitising treatment for steel, and softens and toughens the iron in a somewhat similar manner. When carried as high as 650° C., the iron becomes soft and machinable in the absence of "chill" or free cementite.

The effect of more moderate tempers is a lesser drop in hardness associated with a notable increase in tensile properties, especially in the case of alloy irons. The best range of tempering temperatures appears to be from 400° C. to 500° C., and the increase in tensile strength may be of the order of 10 tons per sq. in. Indeed, high-duty irons of the type under discussion depend in no small measure on this ready response to a quench-temper cycle on the above lines for their superior qualities.

Plans for the Post-War Marketing of Tin

THE major problem facing the industry is to build up an organisation which will create a market sufficiently wide to maintain producers at a reasonable level of activity. This requires a consumption approaching 250,000 tons of tin annually. In financial terms, the pre-war market for, say, £30,000,000 per annum has to be re-established, and over and above this an additional market for upwards of £20,000,000 worth of new tin annually has to be discovered and developed. A selling task of considerable magnitude.

This is the key note of a recently published report describing a plan worked out by Mr. John Ireland, Director of the Tin Research Institute. It is shown that sales depend on the satisfaction of the ultimate consumer and that where better service can be given, expanded consumption follows.

The proposed scheme will harness to the problem of increasing the usefulness of tin, the full resources of a modern scientific organisation. This will comprise a nucleus of scientists whose fundamental work will be carried to the stage of practical application by research teams working on a semi-industrial scale under the guidance of committees representing each of the principal tin-consuming industries.

The report explains the proposed post-war organisation in detail, and summarises the technical developments already made in all the main fields of consumption. It gives the technical grounds on which are based the reasons for expecting to restore those uses of tin abandoned or curtailed during the present scarcity. The report also indicates some promising new uses arising out of the Institute's researches, and gives quantitative estimates of the increased sales that may be expected as the result of the new organisation's activities at the end of a 10-year period.

The budget recommended for these activities is £300,000 per annum, to cover research, development, world-wide technical service, and full-supporting publicity.

Survey of Liquid Steel Temperatures in Basic Open-Hearth Furnaces

By D. Manterfield

(Messrs Steel, Peech and Tozer.)

A temperature survey of the larger type of basic open-hearth furnaces is reported. In the first part details are given of the type of furnace and slag dealt with in the survey. The second part concerns the temperature fluctuations during the progress of a heat. The uniformity of temperature in the bath is shown to be governed by its activity. The report is given here in an abridged form.*

SURVEYS of temperature distribution in a number of types of furnace have already been carried out on acid open-hearth furnaces and various types of electric furnaces. Some details of preliminary work were published in the Second Report of the Liquid Steel Temperature Sub-Committee,¹ and further details were given in the Third Report² of that Sub-Committee. Oliver and Land³ considerably extended this work on the smaller acid open-hearth and four types of electric furnace. The subject was still further extended by Hatfield⁴ in his contribution to the discussion on the latter paper.

In addition, the physical and chemical properties of basic slags show some variation between high and low-carbon charges. In consequence, an endeavour was made in the present survey to cover a number of different steel qualities. Temperature control was being exercised during the period covered by these investigations.

Type of Furnace and Slag

The furnaces were 87-ton cold-charged basic open-hearths of fixed type, fired by producer gas. Coke-oven gas was available for enrichment of the producer gas as and when required. The air and gas ports were as shown in Fig. 1 on all furnaces except one, which was of the Maerz type.

As previously stated, the type of slag varies somewhat with the steel composition. The slags on low-carbon charges are usually higher in FeO content than those on high-carbon charges and their thermal conductivity would also vary in consequence. The average slag thickness would be about 5 in., though slags up to 9 in. thick have been encountered. Some slag temperatures and time-temperature surveys are included in this investigation, and reference is made to these in a later section.

A simplified diagram of a typical furnace, showing the positions explored is given in Fig. 1.

Apparatus and Procedure

Duplicate pyrometers of the Schofield-Grace quick immersion type were available for use. These are in operation for routine control, and all the tests were made by experienced operatives under supervision. The main arm of the couple is 15 ft. long, and the vertical portion is protected by the usual carbon end-block, necessary for basic slags. Approximately half the arm is protected by diatomite insulating blocks, and the rare-metal couple wires are taken to the cool end of the arm, whence compensating leads run to the potentiometer. It was necessary to construct a special long arm to reach the positions near the back bank (G, H and K, Fig. 1). This was 21 ft. long and was protected for half its length by a paste of insulating cement and siliceous clay applied 1 in. thick. In addition, this carried a long carbon block (2 ft. long) to enable the tests at 18 in. deep to be taken without damage to the arm or insulation. New couples were used at the beginning of each experiment and renewed at least once during the course of each individual series. No couple used would thus have a total immersion time greater than 120 secs.

Three portable type potentiometers were used for taking the measurements, and these have been found

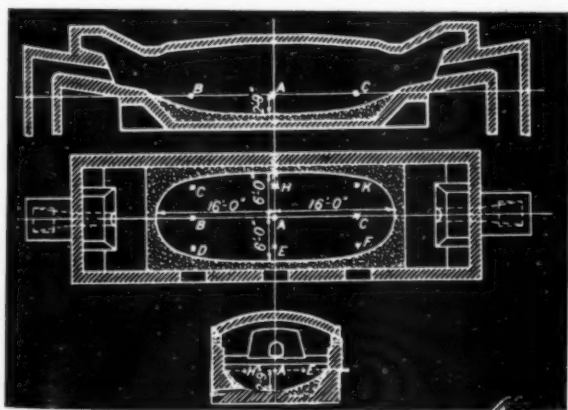


Fig. 1.—Typical furnace showing the positions explored.

The object of the present work was to continue this experimental work by temperature explorations in the larger type of basic open-hearth furnace. It was thought that the difference in the hearth and the slag composition and in the technique of the basic process might cause some variation at different stages of the process and at different positions in the bath.

Previous work by the author had already demonstrated the temperature variation with the carbon con-

* Paper No. 23/1943 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee), published by The Iron and Steel Institute, October, 1943. (Advance copy.)

1 P. H. Schofield and A. Grace. Second Report of the Liquid Steel Temperature Sub-Committee (Eighth Report on the Heterogeneity of Steel Ingots). The Iron and Steel Institute, 1939, Special Report No. 25, pp. 235-261.

2 Third Report of the Liquid Steel Temperature Sub-Committee, Journal of the Iron and Steel Institute, 1942, No. 1, p. 213P-243P.

3 D. A. Oliver and T. Land. Journal of The Iron and Steel Institute, 1942, No. 1, pp. 245P-259P.

4 W. H. Hatfield. Journal of the Iron and Steel Institute, 1942, No. 1, pp. 264P-272P.

to be sensitive, stable and accurate. Before commencing the tests, and several times during the period occupied by the investigation, these instruments were calibrated.

The vertical and horizontal surveys were made separately.

The positions at which immersions were made are shown in Fig. 1, positions B, A and C being on the longitudinal centre-line of the furnace and E, A and H on the transverse centre-line. The deepest part of the bath was 2 ft. 9 in. and was approximately at position H, just over the tap-hole. Owing to the slight slope of the bath from the front banks to this position, the greatest depth that could be safely achieved at positions D, E and F was 15 in., though one or two readings were taken at 18 in.

The procedure for the vertical survey, therefore, was to take measurements at two positions simultaneously at three depths with the special long arm and at two depths with the short arm. On withdrawal, the silica sheath on one instrument was quickly changed and the arm inserted in the third door. This could be done very quickly and there could be little or no change in temperature during the 2 mins. which elapsed between the immersions. The long and short arms were used alternately at the different positions; hence, during the series of tests each position was explored on several occasions.

For the horizontal distribution the two shorter-arm instruments were used at a standard depth of 9 in. As these arms would not reach past the centre-line, positions G, H and K were not surveyed. Figures for these positions at 9 in. depth, for comparison with the centre-line positions B, A and C, are available in the vertical survey. The technique adopted here was to insert two instruments simultaneously and take temperatures at two positions. On withdrawal, the sheath was quickly changed and this machine used through the third door. This was alternated between the middle and each end door.

In the vertical survey some measurements were taken from the top downwards and others from the bottom

upwards. Little or no difference could be found by the two procedures. In the horizontal tests, in some cases the middle-line positions were explored first and in others the positions near the front bank. Again little or no difference could be discovered in consequence.

The measurements were made at three stages—viz., at melting, at going-on, and at tapping—and various furnaces and steel qualities were surveyed. Notes were made of the gas direction, bath condition and finishing additions. With the exception of finishing additions on two or three occasions, no measurements were taken after any bath additions until it was considered that sufficient time had elapsed for approximate equilibrium to be attained.

Results of Temperature Survey

The details of the various tests are given in Tables I and II, with a summary of the deviations in Table III.

These results are not strictly comparable with those of previous investigators, owing to the difference between the technique of the basic open-hearth process and that of the acid open-hearth or electric furnace. The usual procedure on the plant is to add the feed lime as soon as the charge is clear melted, followed by the necessary fluorspar addition. When this is fluxed the predetermined quantity of mill scale or ore is fed as quickly as the furnace will take it. From this point little or no further feed is necessary.

Nevertheless, the tests yield ample confirmation of the conclusions reached by Oliver and Land³ and by Hatfield.⁴ In addition, one or two other interesting points were indicated.

When the bath is uniformly active the spread of results is comparatively small. The carbon content of the steel in conjunction with the temperature and the slag condition will be an indication of the vigour of the boil. Carbon figures are given in Tables I, II, and III, and it will be seen that the range of temperature measurements bears some relationship to the figures quoted.

With the exception of tests 2 and 5 (low-carbon melts) the temperature taken at the standard position was in

TABLE I.—VERTICAL DISTRIBUTION OF TEMPERATURE IN 87-TON BASIC OPEN-HEARTH FURNACES.

Exp. No.	Melted.						Going-on.					
	Position.	Depth, In.	Gas.	Bath Condition.	Carbon, %.	Temperature.	Position.	Depth, In.	Gas.	Bath Condition.	Carbon, %.	Temperature.
1	H	9	Left to right.	Barely melted.	0.63	°C. 1488	A* 9	Right to left.	Boil subsiding. Ready for tapping. No finishing additions to bath.	0.13	°C. 1589*	°F. 2876*
	H	18		"	"	°F. 2710					°C. 1564	°F. 2847
	H	24		"	"	1491 2716					1583	2882
	A*	9		"	"	1493 2720					1580	2876
	A	15		"	"	1487° 2709°					1576	2869
	G	9		"	"	1501 2733						
	G	18		"	"	1450 2642	G 9					
	G	24		"	"	1450 2642	G 18					
				"	"	1450 2642	G 24					
				"	"	1450 2642						
2	A*	9	Left to right.	Just melted.	0.23	1535° 2796°	A* 9	Left to right.	Steady boil. No finishing additions to bath.	0.21	1613° 2936°	
	A	15		"	"	1529 2784					1593	2900
	K	9		"	"	1528 2782					1589	2892
	K	18		"	"	1523 2774					1587	2889
	K	24		"	"	1492 2718					1600	2912
	B	9		"	"	1551 2824					1586	2887
	B	15		"	"	1543 2810						
				"	"							
				"	"							
				"	"							
3	A*	9	Left to right.	Good melt.	1.50	1508° 2746°	A* 9	Right to left.	Steady boil. Bath ready for finishing additions.	0.75	1556° 2833°	
	A	15		"	"	1505 2740					1555	2831
	H	9		"	"	1503 2737					1555	2831
	H	18		"	"	1503 2737					1555	2831
	H	24		"	"	1499 2730					1555	2831
	B	9		"	"	1511 2752					1554	2829
	B	15		"	"	1518 2764					1550	2821
	C	9		"	"	1521 2770					1555	2831
	C	15		"	"						1554	2829
				"	"							
4	A*	9	Left to right.	Just melted.	0.35	1540° 2804°	A* 9	Right to left.	Boil subsiding. No finishing additions to bath.	0.13	1555° 2831°	
	A	18		"	"	1531 2788					1546	2816
	H	9		"	"	1536 2796					1555	2831
	H	18		"	"	1534 2793					1555	2831
	H	24		"	"	1529 2784					1553	2827
				"	"							

* Standard position.

remarkable agreement with the mean of all temperatures in the individual survey. Of the 18 individual tests taken, no fewer than 14 were within $\pm 6^\circ \text{C}$. (11°F .) and 9 were within $\pm 3^\circ \text{C}$. (5°F .). Of the four which exceeded $\pm 6^\circ \text{C}$. (11°F .), three were on the lower-carbon melts and one was after the addition of finishings.

The mean deviation on all the tests was 5.5°C . (9.9°F .). A single measurement made at the standard position can therefore be taken as a representative figure for the bath. This is very gratifying from the viewpoint of temperature control in practice. Furthermore, this gives added confidence in the use of such temperatures for physico-chemical investigations.

In the vertical explorations the temperature naturally decreases with the depth. The maximum temperature gradient in the present series is 26°C . (47°F .) per foot; this was in test 2, where the bath conditions were obviously abnormal. The average gradient of the tests in the vertical survey is 12.5°C . (22°F .) per foot; excluding No. 2, however, the average is 9°C . (16°F .) per foot. This gradient will vary in different furnaces with the thermal conductivity of the hearth—i.e., with the type, thickness and insulation.

In the horizontal distribution there is a wider range than was anticipated. There is a definite tendency for the bath at 9 in. depth to be hotter at the gas inlet than at the gas outlet. This would vary with the pitch, velocity, length and direction of the flame and with the type and thickness of the slag. It will be noted that in tests 3, 6 and 7, which would carry thicker and more viscous slags, there is little difference between the two ends. In the remainder of the tests the gas end averages approximately 10°C . (18°F .) hotter than the other end.

In the majority of the observations the temperature of the bath was rather higher near the front bank than at the centre. Oliver and Land³ had noted the tendency for the edges of the bath to be hotter than the centre, but the present survey showed this only at the front bank. This may be due to the front bank being rather thicker than the back, but the flame also had an influence in some cases, as in test 5 which shows the greatest

increase; here the gas was fanning towards the front lining, and the hottest points were at the tail end of the flame. It will be noted that in this respect the higher-carbon baths (with more viscous slags) had the least temperature variation.

The deviation of the standard temperature measurement from the mean of all other positions showed little or no difference at the three stages of the refining process. Immediately prior to the melt considerable variations will obviously occur, as shown in experiment No. 1. These variations are rapidly reduced as the bath becomes fully melted. At the going-on stage the uniformity depends upon the activity of the bath and the effect of the flame. After normal finishing additions this uniformity was quickly restored, provided that sufficient carbon was present to agitate the bath. Test 8, with very low carbon, had a range of 27°C . (49°F .) 5 mins. after the addition of 10 cwt. of ferro-manganese.

No opportunity occurred during the tests to take measurements after the bath had been quiescent for a sufficiently long period to investigate temperature gradients under these conditions.

Fluctuations of Temperature During Refining

A series of time-temperature observations were made to investigate the temperature variations during the refining process due to bath additions. A number of the curves giving the essential details are reproduced in Fig. 2. It is apparent that only a relatively small degree of superheat is necessary in the basic open-hearth for the reactions to proceed satisfactorily. Calculations of the melting-point of the metal before commencing to feed indicate that the bath was approximately 40°C . (72°F .) above its freezing point at this stage.

Slag Temperatures

An investigation was also conducted on the relative slag and metal temperatures. It was necessary to replace the silica sheath by a graphite sheath for use with basic slags. Preliminary experiments gave steel temperatures $10\text{--}15^\circ \text{C}$. ($18\text{--}27^\circ \text{F}$.) lower with a graphite sheath than

TABLE II.—HORIZONTAL DISTRIBUTION OF TEMPERATURE IN 87-TON BASIC OPEN-HEARTH FURNACES.
ALL TEMPERATURES MEASURED AT A DEPTH OF 9 IN.

Exp. No.	Position.	Melted.				Going-on.				Tapping.			
		Gas.	Bath Condition.	Carbon, %.	Temperature.	Gas.	Bath Condition.	Carbon, %.	Temperature.	Gas.	Bath Condition.	Carbon, %.	Temperature.
					$^{\circ}\text{C}$. $^{\circ}\text{F}$.				$^{\circ}\text{C}$. $^{\circ}\text{F}$.				$^{\circ}\text{C}$. $^{\circ}\text{F}$.
5	A ^o	Right to left.	Just melted.	0.29	1528 ^o	Left to right.	7 mins. after reversal.	0.16	1570 ^o	Left to right.	5 mins. after reversal; no finishings to bath.	0.08	1600 ^o
	B				2782 ^o				2858 ^o				2912 ^o
	C				1532				1572				1598
	D				2790				2862				2908
	E				1534				1562				1605
	F				2794				2844				2920
					1564				1594				1612
					2848				2884				2934
					1534				1594				2901
Gas fanning towards front lining.													
6	A ^o	Left to right.	Well melted.	1.01	1554 ^o	Right to left.	Steady boil.	0.84	1587 ^o	Left to right.	6 mins. after addition of 31 cwt. ferro-manganese.	0.64	1579 ^o
	B				2827 ^o				2889 ^o				2874 ^o
	C				1553				1587				1582
	D				2827				2889				2880
	E				1544				1594				1592
	F				2812				1581				2898
					1555				1592				2889
					2831				1595				—
					1549				1595				—
					2820				1595				—
					1528 ^o				1572 ^o				1585 ^o
7	A ^o	Left to right.	Well melted.	1.25	2782 ^o	Right to left.	Steady boil.	0.62	2862	Left to right.	6 mins. after addition of 10 cwt. ferro-manganese.	0.48	2885 ^o
	B				1530				1574				2898
	C				2786				1574				2884
	D				1530				1578				2872
	E				2786				1572				2862
	F				1540				1572				2862
					1542				1574				2862
					2808				1572				2862
					1546				1572				2862
					2815				1572				2862
8	A ^o	Right to left.	5 mins. after addition of 10 cwt. ferro-manganese.	0.08	1605 ^o				2920 ^o				2917
	B				1603				2917				2917
	C				1596				2904				2904
	D				1623				2954				2954
	E				1601				2914				2914
	F				1598				2908				2908

^oStandard position.

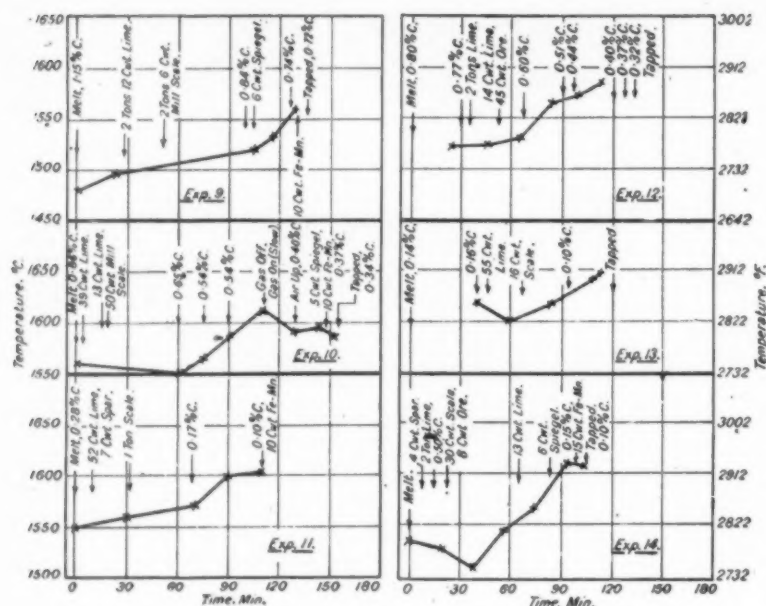


Fig. 2.—Temperature variations during the refining process due to bath additions.

with a silica sheath. By inserting a sillimanite ring between the carbon sheath and the carbon end block comparable results were obtained within $\pm 3^{\circ}\text{C}$. (5°F .), taking simultaneous measurements with each type. These were repeated a number of times before commencing the series of slag temperature measurements to confirm accuracy of the results. In some of the later experiments a small-bore silica sheath was also inserted inside the carbon sheath to ensure that the couple wires could not touch the carbon sheath.

lowest metal temperature at the going-on or tapping period, shows the greatest variation, 47°C . (84°F .), whilst in No. 16, with the highest temperature, the slag was only 1°C . (2°F .) hotter than the metal. Assuming

TABLE IV.—RELATIVE METAL AND SLAG TEMPERATURES.

No.	Bath Condition.	Carbon, %	Metal Temperature.		Slag Temperature.		Difference.		Remarks.
			$^{\circ}\text{C}$.	$^{\circ}\text{F}$.	$^{\circ}\text{C}$.	$^{\circ}\text{F}$.	$^{\circ}\text{C}$.	$^{\circ}\text{F}$.	
15A	Melted.	0.86	1557	2834	1561	2848	4	7	1 hour before tapping.
15B	22 mins. after feed of 2½ tons of mill scale.	0.65	1550	2822	1554	2829	6	10	
15C	30 mins. after 15B.	0.54	1580	2876	1580	2876	0	0	
16	Going-on.	0.18	1637	2980	1638	2982	1	2	
17	Going-on.	0.30	1606	2922	1613	2936	7	14	
18	Tapping.	0.10	1580	2894	1627	2960	37	66	
19	Going-on.	0.68	1571	2860	1618	2944	47	84	
20A	Going-on.	0.14	1579	2874	1613	2936	34	62	
20B	Tapping.	0.10	1600	2912	1631	2968	31	56	
21	Going-on.	0.31	1605	2920	1631	2968	26	48	

TABLE III.—SUMMARY OF TEMPERATURE DEVIATIONS.

Bath Condition.	No.	Vertical.				Horizontal.			
		Difference, Mean from Standard Position.	Maximum Range at any One Position.	Average Range per Foot at any One Position.	Carbon, %.	No.	Difference, Mean from Standard Position.	Maximum Range of All Positions.	Carbon, %.
		$^{\circ}\text{C}.$ $^{\circ}\text{F}.$	$^{\circ}\text{C}.$ $^{\circ}\text{F}.$	$^{\circ}\text{C}.$ $^{\circ}\text{F}.$			$^{\circ}\text{C}.$ $^{\circ}\text{F}.$	$^{\circ}\text{C}.$ $^{\circ}\text{F}.$	
Melt.	1	- 5 ^a - 9 ^a	14 ^a - 25 ^a	12 ^a 22 ^a	0.63	5	-11 - 20	30 54	0.29
	2	+ 6 - 11	36 64	19 34	0.22	6	+ 3 + 5	11 20	1.01
	3	0 0	4 7	6 11	1.50	7	+ 2 + 3	18 32	1.25
	4	+ 6 - 11	17 30	9 16	0.35	8	—	—	—
Going-on.	1	+ 3 + 5	16 29	18 32	0.13	5	- 8 - 14	34 61	0.16
	2	+18 - 32	20 36	26 47	0.21	6	- 2 - 3	18 32	0.84
	3	+ 2 + 3	4 7	2.5 4.5	0.75	7	+ 2 + 3	6 11	0.62
	4	+ 2 + 3	9 16	7 12	0.13	8	—	—	—
Tapping.	1	—	—	—	—	5	- 4 - 7	14 25	0.08
	2	—	—	—	—	6†	- 6 - 11	13 23	0.64
	3	—	—	—	—	7†	- 8 - 14	17 30	0.48
	4	—	—	—	—	8†	+ 1 + 2	27 49	0.08

Mean Deviation of All Tests, Vertical and Horizontal, from the Standard Position:

Melt, 5.5°C . (9.9°F .), Going-on, 5.3°C . (9.5°F).

^a Excluding G position.

† After finishing additions.

The temperature measurements on the slag were taken at a depth of 2 in. and on the metal at the standard depth of 9 in. The details of the tests are given in Table IV.

During the reaction period the activity of the bath equalises the temperature of both the metal and slag, as indicated in experiment 15. At three stages during this period the greatest difference was 7°C . (12°F). As the depths of the two points at which measurements were taken differed by 11 in. this shows a very small temperature gradient.

Towards the end of the refining process the slag and metal temperatures differed to a much greater extent. The difference would be influenced by the prevailing temperature of the bath at this stage—i.e., the greater the difference in metal and gas temperatures, the steeper the gradient between the slag and metal. Test 19, with the

6 in. of slag in the case of No. 19 and a temperature gradient of 9°C . (16°F .) per foot in the metal, this gives a rough approximation of over 100°C . (180°F .) per foot of slag.

The physical and chemical properties of the slag would have an influence upon the deviation of the slag and metal temperatures. An indication is given of the low thermal conductivity of molten slag as compared with steel by the steep temperature gradients which can be set up through slags averaging 5 in. in thickness.

A Note on the Microstructure of High-Silicon Acid-Resisting Iron

By J. E. Hurst, D.Met., and R. V. Riley, B.Sc., Ph.D.

(Messrs. Bradley and Foster, Ltd.)

An unusual type of etched structure, referred to as the "barley shell" structure, has been described by various investigators of the iron-silicon alloys. The authors have observed it in their examination of commercial iron-silicon alloys containing upwards of 10% silicon, and have recorded some conditions of etching under which it is obtained and some observations on its characteristics in this communication to the Iron and Steel Institute, which is reproduced.*

IN the metallographic examination of the alloys of iron and silicon several investigators have, from time to time, reported the occurrence of an unusual type of etched structure, particularly in the alloys of high silicon content. Corson¹ appears to have been the first to observe "some fine but rather definite marks looking more or less like barley shells" during the examination of the microstructure of these alloys containing upwards of 6% silicon. The same investigator more recently² described further examples of the occurrence of this "barley shell" structure in etched specimens of silicon iron containing from 5 to 14% silicon. Some observations of the conditions under which this structure is produced were given, but no explanation of the phenomenon was attempted. The barley shell needles occurred in the iron-silicon alloys containing 4-14% of silicon and most frequently in the range 8-10% of silicon. They were particularly dense in a specimen

quenched from 1,000° C. The absence of carbon in the alloys tended to suppress the formation of the structure, but quenching of the carbon-containing alloy from 1,000° C. had the opposite effect. The structure could not be eliminated by rubbing on a polishing wheel in the absence of abrasive.

Haughton and Becker³ observed this same type of structure. They commented that it seemed to bear no relation to the constitution and that it was absent more often than otherwise. It appeared in a perfectly haphazard manner both in homogeneous and in duplex alloys, although very rarely in the latter, and it was suggested that it was probably a strain effect.

Experimental

The barley shell structure has been observed frequently by the authors during the examination of commercial iron-silicon alloys containing from 10 to 15% of silicon, 0.10 to 0.60% of carbon, 0.30 to 0.70% of manganese,

* Iron and Steel Inst., Oct., 1942. Advance copy.

¹ Trans. Am. Inst. Min. Met. Engrs., 1928, **20**, pp. 249-300.

² Iron Age, 1941, **148**, pp. 45-49.

³ Jour. Iron and Steel Inst., 1930, No. 1, p. 322.

Fig. 1.—Silicon iron, 14.8% silicon. Normal structure of silico-ferrite and graphite. Etched with HNO_3 + HF reagent. x 120.

Fig. 2.—Same specimen as Fig. 1. "Barley shell" structure. Etched with picric acid + HF reagent. x 120

Fig. 3.—Silicon iron, 16.1% silicon. Normal two-phase matrix and graphite. Etched with HNO_3 + HF reagent. x 600.

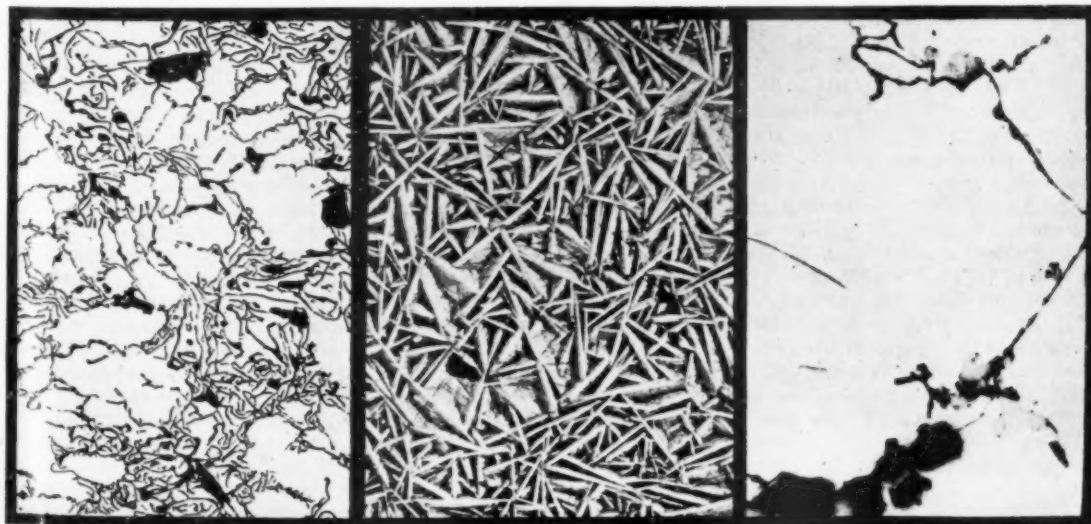




Fig. 4.—Same specimen as Fig. 3. "Barley shell" structure. Etched with picric acid + HF reagent. $\times 600$.

Fig. 5.—Silicon iron, 15.0% silicon. Experiment 10. Etched with alcoholic HNO_3 reagent. $\times 600$.

Fig. 6.—Same specimen as Fig. 5. Experiment 10. "cracked film" structure. Etched with alcoholic HNO_3 reagent. $\times 600$.

and 0.05 to 0.20% of phosphorus. The structure was produced most readily by simple immersion, etching with a picric acid reagent consisting of one part of 5% picric acid in alcohol and two parts of hydrofluoric acid at room temperature for 15–30 secs. Deep etching with this reagent caused a thickening of the barley shell markings. Variations in the strength of the etching reagent and in the time of etching modified the appearance of the structure slightly.

The needles were found to be equally distributed both in the silico-ferrite and in the graphite areas. Under conditions of light etching the needles did not cross interdendritic holes in the specimen, but deeper etching caused a spread of the structure which eventually obscured small holes.

Corson's observation that a particularly dense barley shell structure was produced on a specimen which had been water-quenched from 1,000° C. has not been confirmed, nor does the percentage of carbon in the alloy appear to affect the formation of this structure—an observation which is again contrary to that reported by Corson.

Commercial silicon-iron alloys of the above-mentioned composition consist essentially of a single metallic phase (silico-ferrite) together with graphite. The normal structure of the metallic phase is revealed by immersion-etching with a reagent containing one part of HNO_3 , one part of HF, and six parts of water for a period of 15–30 secs. at room temperature, and is illustrated in Fig. 1. The barley shell structure obtained by immersion-etching this same specimen with the picric acid reagent as detailed above is shown in Fig. 2.

With silicon contents in excess of 15.5%, a second metallic phase appears; the true structure of these alloys obtained by immersion-etching with HNO_3 + HF reagent is reproduced in Fig. 3. The barley shell structure developed on this specimen by etching with the picric acid reagent is shown in Fig. 4.

Under light etching conditions the barley shell structure appears transparent, and under the microscope it is possible by altering the focus to observe either the barley shell needles or either of the normal structures occupying the same field, depending on the silicon content of the specimen.

Treatment of the specimens etched to show the barley shell structure with boiling water and organic solvents did not remove the structure; light rubbing on a dry cloth did not entirely efface it, and after a deep etch the structure survived quite a violent rubbing on a dry cloth. These observations are sufficient to show that the structure cannot be regarded as merely a layer of crystals deposited from the etching solution.

After lightly polishing on a diamantine pad a specimen showing a dense barley shell structure, the tops of the individual needles appeared to have been ground away, leaving flat "plateaux" of micro-dimensions. Further polishing removed the needle structure completely, leaving a flat polished surface. The barley shell structure could be erased completely by a careful second etch with the nitric-hydrofluoric acid reagent and the normal structure of silico-ferrite and graphite revealed.

The results of a number of experiments with different etching reagents and treatments are recorded in Table I. It was found that the barley shell structure could be produced by several etching reagents containing hydrofluoric acid either on immersion or on electrolysis. In the case of pure hydrofluoric acid itself, under conditions of immersion, "normal" etching was recorded and the barley shell structure was produced only on increasing the intensity of the attack of this reagent by electrolytic etching (Experiment 8). The nitric-hydrofluoric acid reagent in the concentration commonly used for the etching of high-silicon irons behaved in a similar manner, and with this reagent the barley shell structure could be obtained either by electrolytic etching or by increasing the acid concentration of the reagent (Experiments 11

TABLE I.—ETCHING RESULTS.

Experiment No.	Etching Reagent.	Type of Etching Produced.	
		On Immersion.	On Electrolysis.
1	1 part 5% picric acid in alcohol : 2 parts HF	"Barley shell" structure	"Barley shell" structure
2	1 part 5% picric acid in alcohol : 1 part HF : 6 parts alcohol	Very faint "barley shell" structure	"Barley shell" structure
3	1 part acetic acid : 1 part HF : 1 part H ₂ O	No etching	"Barley shell" structure
4	4 parts acetic acid : 4 parts HF : 1 part HNO ₃	"Barley shell" structure	"Barley shell" structure
5	1 part tartaric acid : 1 part HF : 2 parts H ₂ O	No etching	"Barley shell" structure
6	1 part tartaric acid : 1 part HNO ₃ : 2 parts H ₂ O	No etching	"Cracked film" structure
7	Pure concentrated HNO ₃	No etching	"Cracked film" structure
8	Pure concentrated HF	"Normal" etching	"Barley shell" structure
9	1 part HNO ₃ : 6 parts alcohol	No etching	No etching
10	1 part HNO ₃ : 3 parts alcohol : 5 parts H ₂ O	No etching	"Cracked film" structure
11	1 part HNO ₃ : 1 part HF : 6 parts H ₂ O	"Normal" etching	Faint "barley shell" structure
12	1 part HNO ₃ : 1 part HF : 1 part H ₂ O	Weak "barley shell" structure	"Barley shell" structure
13	1 part H ₂ SO ₄ : 4 parts H ₂ O	"Normal" etching	"Cracked film" structure
14A	2 parts HF : 1 part 5% picric acid in alcohol : followed by—	"Barley shell" structure was dissolved away and "normal" etched structure remained.	—
14B	1 part HNO ₃ : 1 part HF : 6 parts H ₂ O		

NOTES.—(1) In all cases of immersion and electrolysis the period of etching was from 10 to 30 secs. at room temperature.

(2) A "normal" etching is one showing areas of π iron and graphite only, with no trace of "barley shell" or "cracked film" structure.

(3) The reference to electrolysis implies that the specimen was made the anode in the liquid specified. A current of 8 v. was applied to the circuit.

and 12). The barley shell structure produced by the concentrated nitric-hydrofluoric acid reagent (Experiment 12) was obliterated and the normal structure developed by the dilution of this reagent with water ;

similarly, in Experiment 14 the barley shell structure obtained by the picric-hydrofluoric acid reagent was removed and the normal structure revealed by a following etch with nitric-hydrofluoric acid reagent of the normal concentration as used in Experiment 11.

Certain etching reagents free from hydrofluoric acid produce structures which, although possibly different, under certain conditions may be confused with the true barley shell structure and, like it, do not represent the true phases present in the alloy. An example is given in Fig. 5, which shows the appearance of a specimen of 15% silicon iron electrolytically etched in a solution of one part of nitric acid, three parts of alcohol, and three parts of water (Experiment 10). The same specimen more deeply etched by this same reagent exhibited a "cracked film" appearance, as illustrated in Fig. 6. In order to differentiate between this and the barley shell type of structure it is referred to in Table I as the "cracked film" structure and its appearance with certain other reagents is recorded.

Conclusions

The recorded experimental observations lead to the conclusion that the so-called "barley shell" and "cracked film" structures obtained under certain conditions of etching iron-silicon alloys of high silicon content are not the true structures of the alloys. Whilst the exact nature of these structures has not been determined experimentally, the authors' observations lead them to the view that they are both of film-like character and that their comparatively easy and rapid formation under the observed conditions is a characteristic of high-silicon iron alloys.

The Constitution of Magnesium-Manganese-Zinc-Aluminium Alloys in the Range 0.5% Magnesium, 0.2% Manganese, and 0.8% Zinc

IV.—The Equilibrium Diagram Below 400°C

A FURTHER investigation of the structure of aluminium-rich magnesium-manganese-zinc-aluminium alloys is described in a recent paper,* by A. T. Little, Dr. G. V. Raynor, and Dr. W. Hume-Rothery; it is concerned essentially with the structures of the alloys in the (528) range at temperatures below 400°C. In some cases alloys containing much higher percentages of the solute elements have been examined and are also described. The same system of nomenclature is used as in the previous papers,^{1, 2, 3} and the equilibrium diagrams of the various binary and ternary systems, from which the quaternary system is derived, are again considered.

The equilibrium diagram of the system aluminium-magnesium at the lower temperatures is based on the

work of Dix and Keller⁴ and of Fink and Willey.⁵ This diagram is of such a nature that alloys in the (500) range are all homogeneous about 260°C., but at lower temperatures two-phase alloys of the (α + Mg₂Al₃) type are found.

In the system aluminium-manganese, the solubility of manganese at 400°C. is of the order of 0.01%, according to Dix, Fink and Willey⁶; at lower temperatures it is vanishingly small and it may be said that in the (020) range alloys containing more than the most minute traces of manganese are, at equilibrium, of the (α + MnAl₆) type, the whole of the manganese being present in the form of the compound Mn₂Al₆, which is of fixed composition.

The equilibrium diagram of the system aluminium-zinc

* Jour. Inst. Metals, 69, p. 467. (November, 1943.)

1 E. R. Butcher, G. V. Raynor and W. Hume-Rothery. J. Inst. Metals, 69,

p. 209.

2 G. V. Raynor and W. Hume-Rothery. J. Inst. Metals, 69, p. 415.

3 A. T. Little, G. V. Raynor and W. Hume-Rothery. J. Inst. Metals, 69,

p. 423.

4 E. H. Dix, Jr., and F. Keller, Trans. Amer. Inst. Min. Met. Eng., Inst. Metals Div., 1929, 351.

5 W. L. Fink and L. A. Willey. Trans. Amer. Inst. Min. Met. Eng., 1937,

124, 78.

6 E. H. Dix, Jr., W. L. Fink and L. A. Willey. Trans. Amer. Inst. Min.

Met. Eng., 1933, 104, 335.

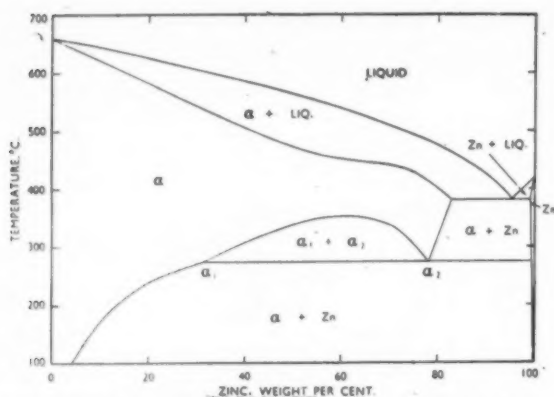


Fig. 1.—The constitution of aluminium-zinc alloys.

is taken from the recent review by Raynor.⁷ All alloys in the (008) range are in the homogeneous α field above about 150° C., and it is only at the lowest temperatures that two-phase alloys are found under equilibrium conditions, the two phases being α and a zinc-rich solid solution which contains only very small proportions of aluminium. The outstanding characteristic of the system is the existence of a range of alloys consisting of a mixture of α phase of two different compositions. This type of alloy exists only between the temperature limits 275° and 355° C., and this part of the equilibrium diagram is now well established. The effect of this phenomenon on the equilibrium of ternary alloys of aluminium, zinc and a third element does not seem to have been discussed, and the authors deal with this question, although the alloys concerned are outside the (528) range. Thus, part of the system aluminium-magnesium-zinc is examined in detail.

The System Aluminium-Magnesium-Zinc.—The isothermal sections of the equilibrium diagrams at 400°, 350°, 300°, and 200° C. are shown. The main feature of the diagram in the (508) range is the characteristic boundary separating the α and ($\alpha + T$) fields, where T stands for the ternary solid solution based on the composition $Al_2Mg_3Zn_3$. This boundary is of the form—

$$[Mg][Zn] = K$$

where $[Mg]$ and $[Zn]$ are the atomic percentages of magnesium and zinc respectively. This relation holds

TABLE I.

Temperature, °C.	400°.	350°.	300°.	250°.
K	8.71	3.35	1.73	0.417

This table gives the value of K in the equation $[Mg][Zn] = K$, where $[Mg]$ and $[Zn]$ are the atomic percentages of magnesium and zinc, respectively, along the ($\alpha + T$) isotherms at the temperatures concerned. The equation does not hold for the lowest percentages of zinc.

accurately for zinc contents greater than 1 atomic per cent. The values of the constant K at the different temperatures are shown in Table I, and a graph is shown in which $\log_{10} K$ is plotted against $1/\theta$, where θ is the absolute temperature; this shows that a linear relation exists between $1/\theta$ and $\log_{10} K$, so that K obeys the well-known relation of the type—

$$\frac{d \log K}{d \theta} = \frac{Q}{R \theta^2}$$

where $Q = 1.3 \times 10^4$ cal. The interest in this lies in the fact that it enables this part of the solubility curve to be calculated at any temperature, except for the lowest percentages of zinc.

Experiments with alloys containing 20 and 60% of aluminium show that alloys of the ($\alpha + MgZn_3$) type are found when the aluminium content is low, but with high percentages of aluminium the $MgZn_3$ phase is never formed under ordinary conditions of annealing. In the binary system aluminium-zinc, the α -solid solution splits up into two face-centred cubic structures of different compositions; this introduces complications into ternary alloys based on the aluminium-zinc system, and some of these are described.

The Quaternary System.—The work on this system was confined to the (528) range of composition, although the principles described in this paper enable the general nature of the diagram to be predicted for higher percentages of the solute elements. In a previous paper³ it was shown that at 400° C., the solubility of manganese was so small that all alloys with more than the most minute traces of manganese contained the compound $MnAl_6$, and the alloys in the (528) range were divided into two classes in which the phases present were ($\alpha + MnAl_6$) and ($\alpha + MnAl_6 + T$) respectively. It was shown that the boundary between these fields could be calculated by assuming that each atom of manganese removed 6 atoms of aluminium in the form of $MnAl_6$, and that the remainder of the alloy could be treated as a ternary alloy of aluminium, magnesium and zinc. In the present paper diagrams and methods of calculation are given by means of which some of the phase-field boundaries in this system can be deduced.

The Iron and Steel Institute

LIEUT.-COL. SIR JOHN GREENLY, K.C.M.G., president of the Institute of Metals, has accepted an invitation to join the Council of the above Institute.

Captain H. Leighton Davies, C.B.E., and Mr. P. B. Brown have been nominated vice-presidents, and Mr. W. J. Dawson and Mr. W. B. Baxter elected members of Council of the Institute.

Letchworth Remembers Stalingrad

LETCHWORTH is to perpetuate the memory of Stalingrad, the great city of Soviet Russia, which Hitler once announced had fallen. Now there hangs in the works of Messrs. Ewart and Son, Ltd., a replica of the Stalingrad sword, which the employees in the tool room have made from scrap metal during their off-duty hours.

Weeks ago the firm and employees were invited to contribute £150 for the endowment of a bed in the proposed new Stalingrad Hospital. Enthusiasm on the part of the directorate and employees has been such that £300 has been raised—enough to endow two beds—and a cheque for this amount was presented by Mr. A. M. Evetts, the general manager, to the Rev. F. Thatcher, Rector of Letchworth, in aid of the Stalingrad Hospital Fund.

⁷G. V. Raynor, *Inst. Metals Annotated Equilib. Diagrams*, Series No. 1, 1943.

The Work of the Joint Research Committees

The above Committees comprise a group of some twenty-three research committees, sub-committees and panels whose aim is to increase current knowledge on steel. They are Joint Committees of the Iron and Steel Institute and the British Iron and Steel Federation, and report to the Iron and Steel Industrial Research Council. A review of their work covering the period 1924-1943, has just been published, but only brief reference can be made here to the wide range and valuable work which has been carried out or is in progress.*

THE Iron and Steel Institute has recently published a review of the work of the Joint Research Committees of the Iron and Steel Institute and the British Iron and Steel Federation, reporting to the Iron and Steel Industrial Research Council for the period 1924-1943. The main concern of these Committees lies with the product not the process, with physical rather than with process metallurgy, but no clear distinction can be drawn, and study of the steel ingot, casting and forged or rolled product inevitably involves also a study of steel in the molten state; while the successful pursuit of certain main lines of investigation is dependent on the solution of subsidiary problems, the perfecting of experimental technique, and the development of special apparatus.

An outstanding feature of the work is the great progress achieved in breaking down barriers which tended to prevent a free interchange of views between various works. The necessities of war-time production have undoubtedly given an impetus to freer interchange of views, but it had long been felt that pooling of research and development and pooling of experience by discussion would result in quicker progress than if each works and each laboratory tried to solve its own immediate problems. The magnitude of some of the problems which emerged as the knowledge of metallurgy increased in itself provided a stimulus for joint effort, especially as the rapid increase of knowledge resulted in a more general understanding of how much still remained to be learned.

Initially, the technique of co-operative research committees had, on the whole, only a limited success; later experience, however, has shown that the interest of the industry and of individuals can be maintained without difficulty, provided that members of committees are made responsible for carrying out specific investigations and communicating results on new work, while the policy of publishing comprehensive reports to include both accounts of work initiated by the committee and papers contributed by individual members, for which the committee takes general responsibility, is instrumental in building up a corporate spirit.

At present the Joint Research Committees comprise a group of twenty-three research committees, sub-committees and panels whose aim is to increase current knowledge on steel. There are four main committees, the Heterogeneity of Steel Ingots Committee, the Alloy

Steels Research Committee, the Steel Castings Research Committee, and the Corrosion Committee.

The Heterogeneity of Steel Ingots Committee was the first to be formed. It began work in 1924 as a sub-committee of the Iron and Steel Institute's No. 5 Committee on Metallography, and has been continuously at work during the twenty years that have elapsed. The Corrosion Committee was constituted in 1928, and was followed in 1934 by the Alloy Steels Research Committee. In that year also the Steel Castings Research Committee was constituted as one of the group. Sub-committees and panels have been set up when necessary.

Organisation of the Joint Research Committees

The success of the Joint Research Committee is largely due to their achievement in securing the voluntary collaboration of companies in the steel and associated industries, of leading officials on their scientific and technical staffs and of scientists in other organisations who have specialised in the subjects under investigation. Some 170 individuals are directly concerned in their work. The initiative in drawing up programmes of research and in carrying them out is in the hands of these members, and is not provided by a central directorate, with the result that the individuals feel themselves to be responsible for prosecuting the various investigations and are not content to leave action in the hands of officials of a central organisation. Membership is personal; officials of companies sit on the committees by virtue of their personal ability to contribute to the discussions and to the investigations, but, naturally, their industrial connections are important factors in determining their qualifications. Every effort is made to see that the committees are truly representative of all relevant industrial and scientific interests. A valuable result of personal membership is that an individual can continue to contribute to the work of a committee even if his industrial employment changes.

The Iron and Steel Institute is now no longer—as it was initially—responsible for providing finance for research, but grants for this purpose are now made by the Research Council from funds put at its disposal by the industry, together with the grant from the Department of Scientific and Industrial Research which is earned on them. The bulk of the expenditure on the researches undertaken by the Joint Research Committees is carried by companies in the industry. Many of these, in addition to subscribing to the Research Council through payments to the Federation and through special grants towards the work of certain committees, incur heavy expenditure on materials and in the time

*The Iron and Steel Institute Special Report No. 29, initially prepared by the late Dr. W. H. Hatfield, F.R.S., and published by authority of the Council of the Iron and Steel Institute at the request of the Joint Research Committee.

spent by members of their staffs. No means are available for assessing the value of these contributions, but they undoubtedly represent a source of income many times greater than the total annual resources of the Research Council. The facilities which industry alone can put at the disposal of research in plant, apparatus and opportunities for practical experiment represent an additional contribution of great value.

The Work of the Committees

The work of each of the four main committees is briefly described in separate sections of the review; lists of reports and papers published by the committees and of their personnel are given in appendices to the various sections. Thus, in Section II the work of the Committee on the Heterogeneity of Steel Ingots is reviewed. The original object of this Committee was to study the problems of inclusions in steel and of the heterogeneity of steel ingots. Work was begun on killed carbon steel ingots, but it was soon extended to include other carbon steel ingots—e.g., those of balanced steel, as well as ingots of alloy steels. At an early date it was found necessary to give consideration also to ingot moulds and to pyrometry, the determination and effect of oxygen and other gases, and to analytical methods. A number of special investigations were authorised, including mathematical studies and numerous theoretical inquiries into the mechanism of freezing.

This Committee now includes within its scope the consideration of all matters affecting the structure and constitution of steel ingots. Some subjects have been entrusted to sub-committees for more detailed investigation, such as:—

- The Ingot Mould Sub-Committee.
- The Joint Sub-Committee on the Physical Chemistry of Steelmaking.
- The Liquid Steel Temperature Sub-Committee.
- The Oxygen Sub-Committee.
- The Inclusions Sub-Committee.
- The Standard Methods of Analysis Sub-Committee.

The review includes the work of these sub-committees.

The work of the Alloy Steels Research Committee, described in Section III, is complementary to that of the Committee on the Heterogeneity of Steel Ingots. No attempt is made to distinguish absolutely between the spheres of activity of these Committees, nor indeed would this be possible. In practice, however, there is little overlapping, largely because a substantial proportion of the members is common to both. The Ingots Committee is concerned primarily with the study of steel ingots and with the occurrence and causes of segregation and of non-metallic inclusions; its investigations are directed mostly to the study of carbon ingots, although ingots of alloy steels have also been examined. The Alloy Steels Research Committee provides opportunities for the detailed investigation of the behaviour and interaction of the different elements, account of which has to be taken in modern steelmaking. While such matters as the constitution and occurrence of sulphides and manganese and the reactions between molten steel and slag are dealt with by the Ingots Committee, it is a function of the Alloy Steels Research Committee to examine the constitutional diagrams of other alloying elements. Particular attention is directed also in the investigations of the Alloy Steels Research Committee to changes brought about in heat-treatment and forging—subjects entirely outside the scope of the

Ingots Committee. In the case of both Committees the necessity of developing facilities needed for the satisfactory study of the major problems or the urgency of certain practical applications within the main fields of investigation have led to the intensive pursuit of subsidiary inquiries, these often being referred to sub-committees.

Section IV concerns the work of the Steel Castings Research Committee. Research begun in 1927 had as its object improving the quality of steel castings with special reference to such defects as blowholes, porosity, flaws, cracks, pits and non-metallic inclusions. Prominence was given to Service and Admiralty requirements. In some cases these requirements made severe demands on steel foundries owing to a necessary combination of intricacy of design and exacting conditions in the use of castings which were required to be as light as possible.

As work progressed, increasing attention was given to its industrial aspects, and the investigation became a general research into the improvement of steel castings from the points of view both of the manufacturer and user. Steel castings of medium size only were originally considered. On the basis of details of manufacture and testing, and records of the effect of modifications of moulding and casting procedure, a survey was undertaken of the most commonly occurring and most dangerous defects to which steel castings in common supply were liable. This work was carried out in the Research Department, Woolwich.

On reconstruction in 1934, it was decided that work could most usefully be pursued by individual and intensive study of the various basic factors which enter into the production of steel castings. This objective has been interpreted in a wide sense and has led to an extensive programme of research, the studies of individual members being pooled and arrangements made for certain factors to be investigated at various non-industrial laboratories. Some fifteen groups of researches have been included in the programme. Since the outbreak of war, however, work has been directed largely to matters of current importance, and, especially through the sub-committees, assistance has been given to the responsible Controls.

The work of the Corrosion Committee is described in Section V. This Committee from its inception employed a special staff, including an official investigator, and, alone of the Joint Research Committees, has since 1930 maintained laboratories, located in Birmingham, devoted exclusively to furthering its objects. Subsequent extensions in connection with special researches are referred to in the appropriate sections. The official investigator is in general charge of all investigations carried out directly by the Committee, and has been associated with much of the work done independently by members and collaborating organisations.

The objects of this Committee were:—

1. The study of the corrosion of ordinary steels are affected by variation in composition, by methods of manufacture, and by conditions of use.
2. The study of corrosion problems arising from steam practice, including high temperatures, as regards superheaters, etc.
3. Critical consideration of rust-resisting and allied steels.
4. Any other matters relevant.

The work now under the direct control of the Committee is mostly concerned with the study of certain

aspects of atmospheric corrosion, other work on the general problem of understanding and preventing corrosion having been put into the hands of the following Sub-Committees:—

Laboratory (Corrosion) Research Sub-Committee.

Protective Coatings Sub-Committee.

Sub-Committee of Low Alloy Steels.

Sub-Committee on the Corrosion of Buried Metals.

In addition to the review of work carried out, reference is made, in the various sections, to researches now in progress. It is apparent after even a casual examination of this review that the Joint Research Committees have greatly increased current knowledge on steel.

The Constitution of Silver-Magnesium Alloys in the Region 0-40 Atomic Per Cent Magnesium

THE general form of the equilibrium diagram of the system silver-magnesium has already been established in the range 0-60 atomic per cent. silver, and the diagram given by Hansen,¹ based mainly on the work of Schemtschushny,² is reproduced in Fig. 1. Saeftel and Sacks³ concluded that the α/β' eutectic did not exist, and that a single solid solution extended from 0-60 atomic per cent. magnesium; but the X-ray work of many investigators has established the distinction between the α (face-centred cubic) and β' (body-centred cubic) phases, and there is little doubt that Saeftel

and Sachs were in error. The equilibrium diagram has not, however, been determined with accuracy, and the results of a study of the system are reported by Dr. H. K. Andrews and Dr. W. Hume-Rothery.* This work was stopped by the war, but it is thought that sufficient information has been gained to justify publication of the results obtained for the equilibrium diagram above 300°C., in the range 0-40 atomic per cent. magnesium.

At 200°C. very curious results have been obtained which suggest that the α -phase, in the region of 25 atomic per cent. magnesium, acquires an ordered structure on very slow cooling or on long annealing; but it has not been possible to investigate this problem further. The existence of a super-lattice at the composition Ag_3Mg is quite to be expected, since in the system gold-zinc, where the electrochemical factor is also high, a super-lattice exists at the composition Au_3Zn .

The results of cooling-curve experiments are plotted in Fig. 2. The primary arrest points are well defined, and should not be in error more than $\pm 0.3^\circ\text{C}$. as far as the pyrometry is concerned; but, owing to the relatively small atomic weight of magnesium, compared with that of silver, a change in composition of 1% magnesium by weight affects the freezing point by

approximately 20°C ., so that it is probably unjustifiable to claim an accuracy greater than $\pm 0.5^\circ\text{C}$. for the individual points, although the smoothed curve is likely to be more accurate than this for the silver-rich alloys. As will be seen from Fig. 2, the α -liquidus curve falls smoothly to the eutectic horizontal, which was determined as lying at 759.3°C .

by a combination of cooling-curve and annealing experiments. The fortunate

occurrence of an alloy freezing within 4°C . of the eutectic enables the position of the eutectic point B to be established accurately as 33.4 ± 0.2 atomic per cent. magnesium. The eutectic point is thus at the exact ratio of two atoms of silver to one atom of magnesium, and the hypothesis of Stockdale⁴ receives further confirmation from this work.

The results of the α -solidus curve are shown in Fig. 2: it falls smoothly to the eutectic horizontal, and its direction of curvature is opposite to that of the liquidus. It meets the eutectic horizontal at the point C, the composition of which was established at 29.3 atomic per

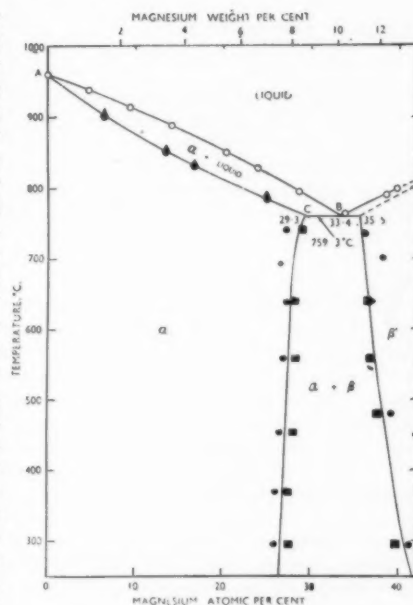


Fig. 2.—Equilibrium diagram by Andrews and Hume-Rothery.

In this diagram all points in connection with the solidus and solid solubility curves refer to specimens analysed after annealing at the temperatures concerned. A large number of less critical alloys inside the various phase-fields were examined, and their microstructures confirmed the diagram.

¹ M. Hansen, "Der Aufbau der Zweistofflegierungen," Berlin, 1936, p. 38.

² F. Schemtschushny, Z. anorg. Chem., 1906, **49**, 400.

³ F. Saeftel and G. Sacks, Z. Metallkunde, 1928, **17**, 258.

⁴ K. W. Andrews and W. Hume-Rothery, Jour. Inst. Metals, **60**, 485, (November, 1943.)

⁴ D. Stockdale, Proc. Roy. Soc., 1935 [A], **157**, 81.

cent. magnesium, with an experimental error which should not exceed ± 0.4 atomic per cent.

The results of the $\alpha/\alpha + \beta'$ phase boundary show that the solubility of magnesium in silver diminishes with falling temperature, and reaches a value of 26.5 atomic per cent. magnesium at 300° C. The solubility limits below 600° C. were, therefore, determined by re-annealing specimens after a preliminary treatment of seven days at 640° C. The times of the final annealing treatments were 10 days at 558° C. and 453° C., and 12 days at 369° C., respectively.

The results for the $\alpha + \beta'/\beta'$ boundary has been established accurately up to 650° C. The intersection with the eutectic horizontal is placed at 35.5 atomic per cent. magnesium. An alloy containing 36.1 atomic per cent. magnesium, after annealing for three days at 738° C., consisted of the homogeneous β' -phase and was satisfactory. This point was known to be very near the solubility curve, because another specimen of the same nominal composition contained a small proportion of the α -phase after annealing at 740° C.

The Suitability of War-Time Coals for Use in Gas Producers

By W. D. Vint

There are few industries in which modifications in technique have not been necessary as a direct result of war conditions, certainly the iron and steel industry would not be included. Differences in the raw materials used have created many problems; even coal supplies have caused difficulties, and since coal, whether in the form of coke or gas, is the source of heat, the importance of suitable types of coal cannot be over-estimated. In our last issue reference was made to coking coal for making metallurgical coke; in the present article attention is directed to gas-producer coal.

WITH the advent of another world war, a remarkable controversial position has arisen between supplier and consumer. No longer can the consumer demand and dictate the exact quality and quantity of his particular requirements, instead, he finds himself in the unenviable position of becoming the recipient of the shortcomings imposed by total war. One redeeming feature is that this change has been wrought gradually, and no one can say there have been no warning rumblings of this approaching scarcity and sparsity of choice of goods.

Of paramount importance in the production of war material we find that coal has not escaped this unwelcome attention, and whether the poor quality which is now making its appearance on the market is due to the government, the workers, or the colliery owners themselves is not a subject for discussion in this short epistle. The immediate concern is for an insight into the possibilities of alleviating these difficulties, also the extent or limit to which the detrimenta can be allowed to creep, the following paragraphs being indicative of the extent to which a circumvention can be made.

Until but recently, coal was subject to rigid and untiring scientific attention before allocation to consumers, but the inevitable lapse of control has now appeared, necessitating action along different lines from that of mere complaint. The particular works upon which this set of conditions has been imposed depends upon the efficient working of two gas producers, of the Morgan revolving hearth type, for its steady output of finished material.

Two Varieties of Coal

Before and during the war, coal from two companies has been used here. To avoid confusion, let us call one variety No. 1, and the other No. 2.

Analyses carried out over a period of years, an average of three analyses for each variety per week indicates but little difference in composition.

	No. 1 Variety.	No. 2 Variety.
Moisture	3.12%	2.84%
Ash	5.80%	4.61%
Volatile matter	35.20%	35.00%
Sulphur	2.13%	1.57%
Fixed carbon	56.87%	58.83%
Calorific value	13,800 B.Th.U./cs.	13,900 B.Th.U./cs.

Analyses were carried out on samples dried at 100° C. for 1 hour.

Both these coals come under the category of gas coals, No. 1 being supplied in the form of peas and No. 2 in the form of nuts. A comparison assessment on the values of these two coals as regards gas-producer work depends upon the three following factors:—

- Analysis.
- Composition of the ash.
- Physical condition.

Calorific value is not important except in so far as a low figure is representative of a high ash.

Analysis

(a) The percentage chemical composition of the two coals shown above indicate fairly good gas-producer coals, but the following range of properties should be borne in mind.

Moisture.—Owing to the difficulty in obtaining a representative sample and also its great variability on account of weather, etc., little significance can be attached to this figure. Generally speaking, the lower the better.

Ash.—This also should be as low as possible, firstly as a preventive against excessive clinker formation, and secondly, that it represents a total loss as far as gas production is concerned. The ash figure indicates total incombustible matter, which comprises the usual

inorganic compounds occluded by the coal plus foreign matter, such as sand, dust, etc., accidentally picked up after processing. Before the war, washed graded coals contained a negligible amount of the latter, but that unfortunately is not now the case. Providing the "ash" figure does not rise above 8% little anxiety can be felt; true, coals containing more than 8% of ash can be used, but the practice is not to be encouraged.

Volatile Matter.—Above 33.0% is to be recommended, and particular note should be taken that the coal is of the non-coking variety. Some producers such as Morgan, Wellman or Chapman can use non-coking coals, whilst anthracite can be used on the Galusha. A derogatory feature of gas coals is a tendency for increasing sulphur content with increasing volatile matter.

Sulphur.—Unlike the anthracites, steam coals and other low volatile coals of good quality, sulphur percentages are liable to run fairly high in gas coals, sometimes as much as 4%. A figure of 3% should be the optimum limit, as above this the corrosive action of sulphur dioxide derived from the splitting up of metallic and organic sulphides causes serious pitting on steelwork in the producer or path of delivery to the furnace.

At the particular works in question, producer gas is used for firing continuous steel billet reheating furnaces in which the products of combustion are in contact with the charge. In this case, high sulphur contents are to be guarded against, as there is considerable danger of sulphur pick-up on the surface of the steel.

Ash Composition

(b) A complete analysis of coal ash presents a long, tedious chemical separation, and the useful information gained rarely warrants the trouble taken. However, from a point of interest, the following is a typical composition:—

Silica	27% to 49%
Titanium	0.03% to 0.09%
Alumina	19% to 39%
Iron oxide	1% to 29%
Magnesia	Up to 0.02%
Lime	1% to 9%
Alkalis	1% to 5%
Sulphates	1% to 11%

In lieu of the analysis the following simple rule can well be adopted:—

(1) Deep brown or reddish ash contains iron oxide with low temperature fusible silicates, and forms much clinker.

(2) White or greyish ash gives little clinker trouble unless it contains much lime.

A high proportion of lime leads to fluxing away of steelwork, whilst alkalis have no effect.

Of major interest in the formation of clinker is the melting point of the ash. This temperature is arrived at by making up the ash into sharp-pointed cones and heating in a furnace, the fusion point being reached when all semblance of cone shape has been lost. Fusion-point values are 150–200° higher in an oxidising atmosphere than in a reducing atmosphere.

Ash fusion point	> 1,350° C.	..	No clinker
"	1,250°–1,350° C.	..	May clinker
"	< 1,250° C.	..	Bad clinker

At this particular works the producers are of a type in which the revolving shell containing the fuel bed automatically discharges clinker and ash into the circulating cooler water. Ash depth is usually about 30 in. with a 9–10 in. fuel bed.

Physical Condition

(c) Since the war, a change has been observed in the physical condition of washed graded coal. It has now been deemed necessary to submit each wagon load to a rigid inspection before discharging into the hoppers. On several occasions wagons have contained such a large proportion of fines with sand and other incombustible materials that the entire contents have had to be rejected. Sand, though not the chief enemy, causes the greatest amount of trouble, and when present, even to the extent of 1%, can cause the formation of a low-fusible troublesome clinker, coating the interior of the producer with glassy silicates. With fairly dry coals the sand is at once apparent on visible examination, and fortunately sinks to the bottom of the wagon, when in the case of side-emptying wagons it can be easily discarded, or segregated from the top layers of good coal. The time and trouble ensued by this extra operation is well worth while, considering the bad effect poor gas-producer working conditions inflict upon rate of heating and production. When discharging wet coal, any sand present is not so easily detected, in which case a small representative sample should be procured, dried and examined. Fine, high-melting point dust can be carried over in the swift stream of gas to its point of application and cause a great deal of trouble, in the instance of billet reheating furnaces a thin glassy silicate being deposited on the surface of the charge with resultant sticking of the billets.

Another feature of poorly washed and graded coals is a tendency for an abnormally high percentage of fines to be present. For the multitudinous purposes to which coal is put, fines are mostly to be deprecated, but in the case of gas-producer work they should be definitely condemned. Fines are almost as troublesome in the dry state as in the wet state. As coal is dropped on to the hearth, dry fines are swept upwards by the steam: air-blast into the culverts and deposited as a thick tarry mass, necessitating not only time and labour in frequent cleaning, but representing a total loss of fuel as far as production of gas is concerned. In the wet state, fines congregate to form large solid lumps containing excessively high percentages of moisture, and it can well be imagined the dampening effect this has upon a small thickness of fuel bed. In several instances producers have been put completely out, but as is most often the case, a general lowering in temperature is experienced with a resultant drop in gas quality.

Dry coal containing a high percentage of fines can be screened, and the extra labour involved in this operation is worth the saving in fuel and the increased efficiency of gas-producer output. For ordinary conditions, using a good dry coal, a fairly thin fuel bed of, say, 8–9 in., can be maintained without danger of a sudden heavy influx of coal greatly lowering gas temperature, but with a very wet coal it is advisable to maintain a thicker bed of, say, 10–11 in.; with this arrangement the dampening effect of wet coal is not so marked.

Gas temperature is particularly important, and at the producer in question a temperature between 700° and 740° C. indicated good working conditions and good quality gas. Air saturation temperature was rarely altered, and a record over a period of months shows but little change. Upon inspection of a 24-hourly chart, showing steam pressure at the producer, great fluctuations due to varying demands on gas output were apparent. Rates of coal input also corresponded to these fluctuations, the latter being controlled by hand

Quality of Gas

Naturally, a prime factor in assessing the general efficiency of a gas producer, this is often overlooked, in some cases producers have been in operation for years without a single check-up on gas quality being made. Providing the means are available, two factors are required at least once per week :—

- (1) Analysis.
- (2) Calorific value.

The filtered sample of gas can be analysed on the ordinary Orsat or Bone and Wheeler type of apparatus, and provides us with a convenient insight into the suitability of steam, air and coal ratios. Obviously, each gas producer has different characteristics, and no laws can be made for a strict adherence to any one particular analysis.

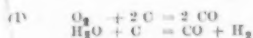
Several items which have a common significance to all, however, can be outlined here. Generally, the following limits of constituent percentages should be made a standard aim :—

CO ₂	> 7.5%
O ₂	> 0.2%
CO	21/25%
CH ₄	3/4-5% (dependent on type of coal)
H ₂	12/11%
N ₂	By difference from 100.

The above analysis applies to high volatile coals only. As the red heat of the fuel bed has to be maintained during operation, the CO₂ percentage is particularly important in that it registers degree of complete combustion of fuel. By increasing air saturation temperature and adjusting rate of coal feed, an abnormally high percentage of CO₂ can be made to conform to the above limit. Little doubt can then be entertained that the minimum quantity of coal is being used to hold the fuel-bed temperature. Excessively high gas temperatures at the off-take is also a sign of too complete a combustion, no higher than 740° C. provides a useful guide.

A higher O₂ figure than 0.2% calls for an increase in air saturation temperature—that is, a decrease in the amount of air. It is to be expected that by increasing O₂ there is a corresponding increase in CO₂, owing to the higher degree of combustion incurred; this is partly true, but from a study of numerous analyses a high CO₂ percentage can be accompanied by a nil O₂ percentage. This is due partly to occluded CO₂ carried by the coal and the overall reduction in volume of the output gas caused by the reduced air volume. A misinterpretation of facts can be made here if the two percentages of CO₂ and O₂ are not taken jointly into account. Gas temperatures also are useful in ascertaining the true cause of unsatisfactory analyses.

The constituent percentages of the three combustible gases CO, CH₄ and H₂ represent the total heat value as far as analysis is concerned. CO always varies inversely as CO₂, its percentage depending upon ratio of air to coal feed. Air saturation temperature (i.e., steam : air ratio) controls CO and H₂ percentages.



The above two equations represent the reaction between the air, steam and red-hot coke respectively.

By lowering saturation temperature—i.e., raising air proportion—reaction (1) is accentuated with a resultant increase in CO; the action being exothermic, there is a general rising in temperature of the fuel bed. By increasing air saturation temperature—i.e., increasing steam proportion—reaction (2) is accentuated with rise in H₂. A lowering of fuel-bed temperature is experienced here as the reaction is endothermic. Owing to the deficiency in air, a partial carbonisation takes place with a release of CH₄. This percentage constituent depends firstly upon the nature of the coal (the higher volatile coals producing higher percentages of CH₄), and secondly, upon the proportions of air to coal feed. The lower the air input, the greater the degree of carbonisation, with resultant increase in CH₄. If the O₂ content of the gas rises above 0.2 there is a rapid falling off in CH₄ content. This is to be expected from the reaction :—



The following set of producer-gas analyses conforms fairly well with the above statements :—

Date.	CO ₂ , %	O ₂ , %	CO, %	CH ₄ , %	H ₂ , %	N ₂ , %	B.Th.U.'s per Cub. Ft.	Lb. of Steam	° C. Temp.	Coal, Cwts./Hour.	° C. Gas Temp.
July 9	8.2	NH	21.2	3.0	14.0	53.6	146	53	53	26	700
10	7.6	0.2	22.5	3.0	12.2	54.5	145	51	50	35	700
11	6.8	NH	22.8	3.0	11.7	55.7	144	38	50	31	680
12	6.6	NH	23.6	4.0	12.3	53.5	159	65	55	35	660
15	6.0	NH	23.8	3.5	12.0	54.7	154	50	58	28	695
16	8.4	NH	21.6	3.5	14.0	52.5	153	45	60	27	700
18	7.2	NH	23.6	4.5	11.4	53.3	161	63	58	30	670
19	6.0	NH	26.0	3.0	14.0	51.0	154	60	58	30	665
23	6.2	0.2	24.8	3.4	12.3	53.1	157	54	56	35	710
24	7.0	0.2	23.8	3.0	13.0	53.0	151	41	41	26	720
25	8.4	NH	21.7	3.5	12.6	53.8	148	62	62	31	710
26	7.6	NH	23.6	4.4	10.0	54.4	156	50	50	40	720

The calorific value of the gas is of prime importance, and naturally should be as high as possible. The calorific values tabulated above are estimated from the individual heat values of the constituent combustible gases. High volatile coals, however, produce much tarry matter, which, carried over by the gas increases its overall calorific value. The total C.V., taking into account this tarry matter, can be found using a standard gas calorimeter, but, generally speaking, the estimated C.V. is good enough for all practical purposes. A useful practical point, applying to high volatile coals, is well worth mention: A yellowish green appearance to the gas denotes high C.V., whilst a thin bluish tint is usually indicative of low C.V.

A concluding paragraph may aptly suggest a formulation of plans for fuel saving and heat conservation devices. These are too numerous for discussion here, but all of essentially simple basis—for example, restricted use of bleeders, reductions in coal feed at warrantable opportunities, lagging of as many heated surfaces as possible, etc. Much can still be done, even on the most modern and economical plants to eke out our limited coal stocks and shoulder this very real burden of fuel and labour scarcity. The fuel-saving target of 8-10,000,000 tons of coal per annum, set by the Ministry of Mines, can quite easily be reached by (1) an intelligent insight into these problems by technical staffs, plus (2) the co-operation of the workers in a conscientious support of their schemes.

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METALLURGIA

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ONE can think of a number of ways in which the authority of British microchemistry, and hence that of British chemistry, could be improved. In particular, some method of distinguishing microchemists is desirable. That some suitable authority should be induced to award a Certificate of Competence in Microchemistry is the logical solution. The Royal Institute of Chemistry would seem to be the obvious choice, since it is generally recognised as our most universal examining body. There is no doubt that the introduction by the Institute of the Fellowship in Analytical Chemistry has done much, and will do more, to enhance the status of the analytical chemist. A similar recognition, in a more humble way would be of equal benefit to microchemists. Not only would the ability of the individual be certified, but it is almost certain that Universities and Technical Colleges would be induced to offer courses suitable for candidates wishing to obtain the Certificate. In these days, when post-war education bulks large in the discussions of chemists, such a minor innovation might well find a corner in the interest of those who believe that microchemistry, in the memorable words of Sellar and Yeatman, is a "Good Thing."

Polarographic Technique: A Survey

By J. T. Stock, B.Sc., A.I.C.

The polarograph, and in particular the recording polarograph, offers a useful means of estimating traces and minor constituents. Many variations in technique may be employed to suit different requirements, and a number of these are described.

METHODS of analysis based on the use of the polarograph present some attractive features. Of these, perhaps the most striking is the very small amount of sample required: the polarograph is essentially a microchemical tool. The strength of the solution with respect to the substance to be determined may be as small as 10^{-5} M, while 10^{-3} M is a good average. Thus, if we consider the polarographic estimation of, say, copper, a solution containing 60 mg. per litre will be ample for examination. Further, the polarograph measures concentration, and not the total amount of the substance present. Hence a very small volume of solution can be used. In fact, polarographic cells have been designed to permit the examination of a volume as small as 0.005 ml., though such devices are needed only in work of exceptional nature. Cells of from 2 to 20 ml. capacity are regularly employed and are available commercially. Hence, using the solution of copper mentioned above in a 2 ml. cell, about 0.1 mg. of metal could be comfortably estimated. It should be emphasised that this is an average amount, and by no means the lower limit. The accuracy of the determination is, in general, within $\pm 2\%$. In view of the small amounts involved, this bears comparison with any other method of analysis. The polarographic method is especially suited for the determination of traces or minor

constituents. To obtain the highest accuracy a thermostat should be used. An elaborate device is quite unnecessary, as control to $\pm 0.2^\circ$ is ample.

The polarograph can be applied to a wide range of substances. Most of the metallic elements have been studied, some extensively; subsequent remarks will be confined mainly to these. It should be mentioned, however, that many organic substances can also be estimated, as well as certain anions, such as cyanide, halogens, etc. Besides affording a means of estimation, the polarograph often permits valuable information as to the nature of the reaction taking place at the electrode to be gained.

Theory, general practice and apparatus have been dealt with in several excellent monographs, as well as in several review papers.^{1, 2} Hence the barest outline only, confined to cathodic reactions, will be considered here.

General Principles

The solution to be examined is electrolysed between a very small cathode and a large anode (Fig. 1). The cathode consists of a steady stream of tiny mercury

¹ Kolthoff, I. M., and Lingane, J. J., "Polarography," New York, Interscience Publishers, Inc. (1941); "Cambridge Polarograph for Micro-Analysis," List 109, Cambridge Instrument Co., Ltd., London; Jeffery, G. H., "Sheet Metal Industries," 1942, **16**, 1525.
² Coates, A. C., and Smart, R., *Chem. and Ind.*, 1941, **60**, 778.

drops issuing from the tip of a fine glass capillary dipping beneath the surface of the solution. In the simplest case the anode consists merely of a pool of mercury at the bottom of the vessel. By means of the battery, the regulating resistance R , and the potentiometer P , any desired potential difference up to a few volts may be applied to the electrodes. The current flowing is indicated by the galvanometer G , the sensitivity of which is controlled by the shunt S . Owing to the growth and fall of the mercury drops the current is pulsating. By choosing a suitable galvanometer and using special damping devices when necessary the pulsations can be almost completely eliminated. It is quite possible to calibrate the galvanometer to read directly in microamperes; for the purposes of analysis, it is usually quite sufficient to express results in terms of "millimetres deflection." Since dissolved oxygen

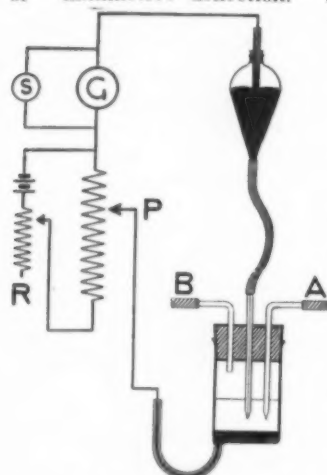


Fig. 1.—The principle of the polarograph.

may interfere, it is removed before the determination is commenced, usually by passing a stream of nitrogen or hydrogen through the solution. In neutral or alkaline solutions the same result may be brought about by adding a little sodium sulphite. The procedure is then to measure the current passing while steadily increasing the applied voltage and hence to construct a current-voltage curve. This can be done by plotting directly on graph paper, but although quite as accurate as any other method, this is a laborious business. With the instruments available commercially the current-voltage curves or *polarograms* are recorded automatically, usually photographically, with consequent saving of time and labour. A polarogram obtained in this way is shown in Fig. 2. It will be observed that at first little or no current flows. As the voltage is increased, the current rises to describe an "S"-shaped curve, referred to as a "wave" or "step." At the summit of the step further increase in the voltage has little effect on the magnitude of the current until the reduction potential of the second metallic ion is reached, when a second step is formed. The heights of the steps are measured as shown, and the concentrations of the metals obtained from the measurements as discussed later. The potential of the mid-point of the step is characteristic for a given metallic ion, and is termed its *half-wave potential*.

In certain cases double or multiple steps are obtained, reduction proceeding in stages. When, as is usual, all the waves have definite half-wave potentials, this does not cause much complication. Humps or peaks, referred to as *maxima*, often appear at the summits of the steps, rendering the measurement of the wave height difficult or impossible. Fortunately, these irregularities can usually be completely eliminated by the addition of a trace of colloidal substance such as gelatine.

While the polarograph certainly permits the simultaneous estimation of several metals, it is by no means correct to assume that all that is necessary is to dissolve up the sample, introduce it into the polarographic cell, and hence obtain a polarogram giving a complete analysis. Such expectations inevitably cause disappointment. However, the purely chemical operations associated with any form of analysis can, in general, be considerably simplified by using polarographic methods. Thus, it is usually sufficient to remove the bulk of an interfering substance; further, when the amount of a precipitate is not too large the supernatant solution can often be drawn off for polarographic examination without the need of filtration. The literature of polarography is

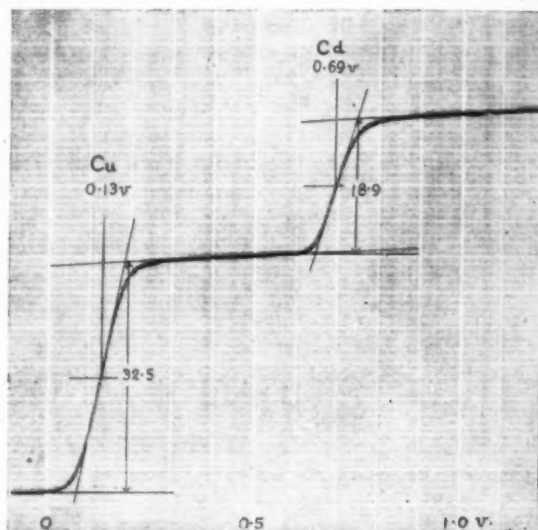


Fig. 2.—Polarogram of copper and cadmium in citrate base solution.

already extensive, hence rather than attempting to list even a representative selection of estimations it would seem more profitable to examine a few points of general technique.

Estimation is almost always carried out in the presence of a large excess—50-fold or more—of so-called *supporting or indifferent electrolyte*—i.e., one which has a much more negative reduction potential than the metallic ion being determined. Though its exact concentration is not important, this should be kept uniform to avoid discrepancies in results. The indifferent electrolyte may be added to the test solution before recording the polarogram, or, by adjustment of the preliminary treatment, the correct concentration of a suitable electrolyte may be automatically introduced. The various methods of introduction are summarised below.

The Use of Base Solutions

The solution to be examined is mixed in definite volume relationship with a previously prepared stock solution which may contain, in addition to the desired indifferent electrolyte, substances whose function is to suppress the undesirable "maxima" and, when necessary, substances which, by complex formation or other means, either improve the shape of the step, separate two interfering ones, or suppress a step entirely, permitting

measurement to be made on those unaffected. Fig. 3 shows the polarogram of a sample of a copper alloy containing 1.1% of cadmium. The base solution used was a citric acid-caustic potash mixture, in which copper gives a well-defined wave. It will be seen that although measurement of the height of the copper step presents no difficulty, it is impossible to distinguish that due to cadmium. In the presence of cyanides both copper and cadmium form complex ions. The copper complex is much the more stable of the two, hence on re-examining the sample in the presence of cyanide at increased concentration and greater galvanometer sensitivity, the cadmium wave appears first. Fig. 4 shows part of the polarogram of the same alloy in a cyanide-containing base solution, the cadmium step now being readily measured.

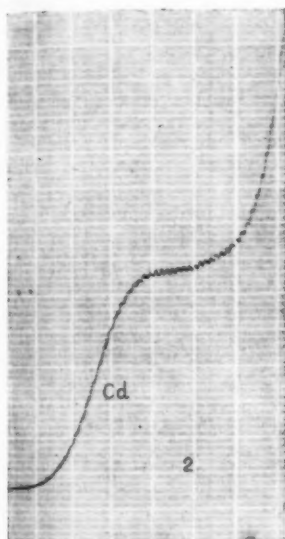


Fig. 3.—Copper containing 1.1% cadmium in citrate base solution.

which may act as indifferent electrolytes, this can often be arranged. Dissolution of a sample in acid, followed by subsequent neutralisation with alkali, provides an obvious example of the introduction of an indifferent electrolyte consisting of a neutral salt. Another is afforded by the determination of copper in aluminium alloys described by Coates and Smart.³ These workers dissolve the sample in a mixture of hydrochloric and nitric acids, and, after boiling off nitrous fumes and cooling, precipitate the aluminium by addition of excess ammonia. Copper is determined polarographically in the filtrate, the mixture of ammonia and ammonium salts acting as the indifferent electrolyte.

Use of a Major Constituent as Supporting Electrolyte

This method, though not so general in application as the other two, has the virtue of being extremely simple. It can be used for the polarographic determination of minor constituents which are more readily reducible than the major constituent. Thus small amounts of lead and cadmium in zinc may be determined merely by dissolving the sample in dilute hydrochloric acid,

removing the dissolved oxygen and recording the polarogram between 0 and -0.9 volt, when the steps of lead and cadmium are obtained. The large excess of zinc chloride acts as the indifferent electrolyte.

The determination of lead in steel, recently described by Haim and Barnes,⁴ is of this type. The sample is dissolved in hydrochloric acid, nitrogen being passed through the solution to avoid oxidation of the ferrous iron. After adding gelatine, the polarogram is recorded between -0.1 and -0.7 volt, ferrous chloride forming the indifferent electrolyte. The saving in time over the normal gravimetric procedure is obvious.

For the purposes of practical polarography, standardisation of procedure is usually carried out by the means of a reference sample or solution of known concentration, the aim being to obtain a relationship between the observed step height and the concentration of the metal to be determined. There are several ways of establishing this relationship.

Direct Comparison

Solutions containing varying concentrations of the metal in question are prepared, the conditions being the same as for the actual test samples. Each of these solutions is then polarographed and the height of the step plotted against the corresponding concentration. A calibration curve is thereby obtained from which unknown concentrations may be read off. The curve is very often linear. The concentration of the test solutions should then be adjusted to fall well within the limits of calibration. Carefully carried out, this method gives very accurate results and is suitable when numerous similar determinations have to be made. The results, of course, depend on the characteristics of the capillary, hence calibration has to be repeated should the capillary be changed. In any case, it is safer to check results daily by polarographing a sample of known concentration.

Method of Standard Addition

Though not so accurate as that described above, this method is suitable when a few isolated determinations have to be made which do not warrant the preparation of a calibration curve. The test solution is first polarographed and then a suitable known volume of a standard solution of the metal to be determined is added. A second polarogram is then recorded. From the increase in step height the concentration originally present may be calculated. Lingane and Kerlinger⁵ used this method to estimate traces of nickel in cobalt salts.

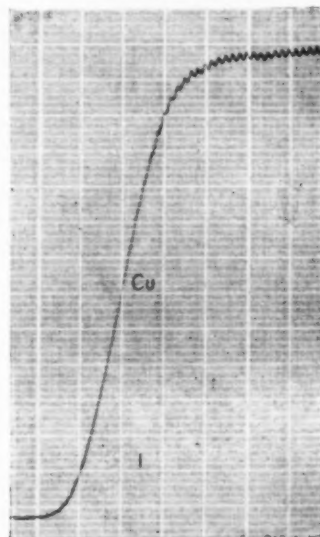


Fig. 4.—Elimination of copper step by use of cyanide base solution.

³ Coates, A. C., and Smart, R. *J.S.C.I.*, 1941, **60**, 249.

⁴ Haim, G., and Barnes, W. C. E. *Ind. Eng. Chem., Anal. Ed.*, 1942, **14**, 867.

"Pilot Ion" Method

The relative step heights obtained with equal concentrations of various metals under the same conditions are constant. Hence if the step height-concentration relationships of a series of metals are known, the concentrations of all can be determined from a single polarogram if the concentration of one is known. The "known concentration" is most simply achieved by the addition of a standard solution, as in the previous case. The substance added need not, however, be one of the original constituents of the solution. Thus lead and cadmium in the same solution might be determined by the standard addition of zinc, since the step height relationships between the three metals have been accurately determined.

This method has been applied to the analysis of brass plate.⁵ The sample is treated with ammoniacal ammonium persulphate to dissolve the plate, and the resulting solution is added to a "base solution" containing ammonia, ammonium chloride, gelatine and sodium sulphite. The latter not only removes dissolved oxygen, but also destroys the excess of persulphate, which would otherwise interfere. Instead of recording the complete polarogram, readings are taken at either three or four predetermined applied voltages, depending on the degree of accuracy required. Only the relative step heights of copper and zinc are needed, the percentage of copper in the plate being obtained from a simple formula after comparison with results obtained using a standard brass solution. Since the method is a relative one, not only is it independent of the properties of the particular capillary in use, but also temperature control is not so important as is normally the case. The authors state that six analyses per hour can be made in routine work.

⁵ Lingane, J. J., and Kerlinger, H. *Ind. Eng. Chem., Anal. Ed.*, 1941, **13**, 77.
⁶ Tyler, W. P., and Brown, W. E. *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 329.

A New Microchemical Instrument

IN recent years the number of instrumental methods of chemical analysis, as distinct from the older, purely bench methods, has increased very rapidly. Twenty years ago, we might truthfully say that there were at the chemist's disposal only emission spectrographic analysis and colorimetry, both in a very rudimentary state of development. Now this select company, much polished, has been joined by polarography, Raman and infra-red spectroscopy, electrometric methods of various natures, X-ray analysis, to mention only a selection. All of these methods provide analytical tools of growing precision and delicacy.

It has recently been reported* that yet another instrument has been pressed into the service of the analytical chemist. A mass spectrometer, constructed on the Dempster 180° principle, has been applied to the analysis of gases and vapours. As yet, the field covered has only been that of the hydrocarbons met with in such regions as the petroleum and synthetic rubber industries. There seems no reason to doubt that extensions to other applications will be a matter merely of adjustment of

* Washburn, Wiley and Rock. *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 541.

Indirect Determination

Metals which yield poorly defined waves, or whose reduction potentials are inconveniently high, are difficult to estimate by direct polarography. Fortunately, indirect methods can sometimes be devised. Sometimes the metal can be treated with a known excess of a reducible precipitant, the decrease in concentration of the latter being determined polarographically. Thus calcium has been estimated in this manner by precipitation with picrolonic acid, the excess of the latter then being determined.⁷

Another interesting method of indirect estimation has been described by Carruthers.⁸ He was interested in the estimation of very small amounts of magnesium. This metal is noted for its ill-defined step, useless for measurement. The sample is treated with 8-hydroxyquinoline ("oxine") under controlled conditions, and the resulting magnesium-containing precipitate dissolved in hydrochloric acid and added to a suitable buffer solution which acts as indifferent electrolyte. By this means 8-hydroxyquinoline equivalent to the magnesium present is introduced into the solution. This substance, unlike magnesium, yields a well-defined wave which is measured under specified conditions and affords a measure of the magnesium present. Dealing with a fraction of a milligram of metal, a maximum error of less than 3% was recorded.

From the few examples quoted, it is obvious that the possibilities of the polarograph are manifold. While again emphasising that each particular analysis needs to be treated on its merits, considerable saving in time and labour usually results. The instrument may then be expected to pay for itself very rapidly.

The polarograms illustrating this article are reproduced by the courtesy of the Cambridge Instrument Co., Ltd.

⁷ Cohn, G., and Kolthoff, I. M. *J. Biol. Chem.*, 1943, **147**, 765.
⁸ Carruthers, C. *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 412.

technique. If this is the case, the mass spectrograph may well be reckoned as one of the most important instruments in chemistry. Chemists are well aware of how much the instrument has told us of the fundamental nature of matter, as exemplified in the brilliant researches of Aston.

In the method of analysis here quoted, it has been possible to analyse 0.1 ml. of such complex mixtures as butane-*iso*-butane-propane-ethane-methane. It is very doubtful if any other technique yet designed could handle a problem of this nature.

Electrographic Analysis

THOSE interested in following up this technique, dealt with at some length in our December number, will find details of tests for a number of metals in a recent publication.[†] There are included tests for bismuth, cadmium, chromium, cobalt, copper, iron, lead, molybdenum, nickel and silver, together with some notes on the interferences to be expected.

[†] Hunter, Churchill and Mears. *Metal Products*, 1942, **42**, 1070; *Analyst*, 1943, **68**, 344.

Production of Alumina from Low Grade Ores

By R. S. Dean

IN an effort to make available the aluminium content of lower-grade domestic resources, notable results have been obtained in the beneficiating of low-grade bauxite; the soda-lime-sinter soda-extraction method for low-grade bauxites and clays, not concentratable, but convenient to limestone deposits and cheap fuel; the ammonium-sulphate-exchange process, which has certain definite advantages; a sulphuric acid process for clay or bauxitic clay; processes for producing alumina from the alunites; and an electric-furnace smelting process for certain high-iron, high-silica bauxites. As no one process is suited to all the possible domestic sources, these named processes and variations, and others, are being investigated simultaneously by the U.S. Bureau of Mines in its pilot plants.

Large amounts of metallurgical-grade bauxite and an increased supply of bauxite containing less than 15% silica can be provided by utilising the bauxite beneficiation procedure developed by the Bureau of Mines. The problem of beneficiation is largely one of rejecting silica. Iron and titanium can be removed by magnetic separation or gravity concentration, but these methods are ineffective for rejection of the silica, so other methods, such as flotation, must be employed. Flotation or a combination of flotation and gravity concentration, would make available to the Bayer process additional quantities of high-grade bauxite concentrate from ores not now utilised.

High-silica bauxites (up to 25%), also containing reasonably high percentages of alumina, are known to occur in Arkansas, Georgia, Mississippi and other southern states. The lime-soda sintering process, sometimes called the Deville process, is being adapted by the Bureau of Mines at one of its experimental stations to these high-

silica materials. Four major steps are involved:—

- (1) Calcination of the bauxite with admixtures of limestone and soda ash.
- (2) Leaching of the sintered bauxite mixture for extraction of the soluble alumina.
- (3) Pressure treatment of the sodium aluminate solution for partial removal of silica.
- (4) Precipitation of the alumina of the desired physical and chemical properties.

In addition to these four operations the final waste solutions, essentially barren of alumina, but relatively high in soda, must be treated to recover the sodium carbonate.

The lime-soda sintering of these bauxites high in silica renders their alumina soluble in water and dilute alkalis in the form of sodium aluminate, but fixes virtually all of the silica in the insoluble dicalcium silicate. Separation of high-purity alumina from these solutions can be done by carbonating. Plants combining the Bayer with the lime-soda sintering process are being designed and constructed, which will use bauxite averaging between 13 and 15% silica. These plants are entirely operable on bauxite carrying even higher percentages of silica, but above a certain percentage the straight sinter process is indicated. The logical extension of the lime-soda-sinter method of producing alumina is to apply it to high alumina clay and other aluminous material.

The essential steps in the ammonium sulphate exchange process are the reaction of a mixture of the pulverised clay and ammonium sulphate at temperatures of 373°–400° C. in a rotary kiln, whereupon the clay reacts to form ammonium sulphate (alum) with the evolution of ammonia, or, by reaction with products of combustion,

ammonium carbonate. The reacted mass is then leached at 95°–100° C. with water and a small addition of sulphuric acid, and the pregnant liquor is separated from the insoluble residue, or sand, which is treated to remove any retained ammonium aluminium sulphate. The hot solution is crystallised in two stages, and the alum crystals are refined by an additional recrystallisation step, then dissolved to provide make-up solution for the aluminium hydroxide precipitators. The alum solution is treated with ammonia or ammonium carbonate formed in the first step to precipitate aluminium hydroxide. The aluminium hydroxide is filtered off and ignited to yield anhydrous alumina, and the ammonium sulphate produced in the precipitator is concentrated and recycled for treating a fresh batch of clay in the rotary kiln and extraction agitator.

Clays can also be treated by several acid processes, one of which was originated and developed in the laboratories of the U.S. Bureau of Mines. The clay or bauxitic clay is leached with strong sulphuric acid, and an impure concentrated solution of aluminium sulphate is obtained by filtering and washing the insoluble residue of silica. A suitable reagent precipitates from this solution relatively pure aluminium sulphate, which is filtered or centrifuged off, dried, and calcined to produce alumina. The reagents are recycled.

A number of processes have been proposed to recover alumina and potash from alunites; among the more important of these are the Kalunite and the Moffat processes. In the Kalunite process the crude ore is crushed and given a dehydrating roast at 550° C. to make it soluble in dilute sulphuric acid. The hot calcine is cooled to 200° C. and given a counter current agitation and leach in a solution of potassium sulphate and 10% sulphuric acid. The counter current leach is operated to maintain an excess of roasted alunite in the first agitator, so that the pregnant solution contains no free acid. This is an

important step in eliminating impurities. The pregnant solution is filtered out and then cooled, normal potassium alum crystallising out. The alum crystals are washed, dissolved with dilute potassium sulphate solution, and treated in a continuous autoclave at a temperature of 200° C. The potassium alum is broken down into a basic alum plus sulphuric acid and potassium sulphate. The acid and potassium sulphate are recycled for the original leach, and the basic alum is calcined to decompose it into alumina and potassium sulphate. This calcine is then leached with hot water to remove the soluble potassium sulphate, leaving behind the alumina. The leach solution is then evaporated to crystallise out potassium sulphate. The essential difference between the Bureau of Mines modification of the Moffat process and the Kalumite process is the substitution, in the former, of flash drying of the alum for treatment in an autoclave. The process with minor modifications is also applicable to clays, shales, and other aluminiferous materials.

Treatment of high-iron bauxite in the electric furnace has been practised successfully on a commercial scale in Norway. The only practical method of making calcium aluminate from high-silica bauxite is by two stages. Silica and iron oxide are first reduced and removed as ferro-silicon in a primary furnace operation. Then the molten slag, containing 95 to 98% of alumina, is transferred to a second furnace, where, with the addition of lime, monocalcium aluminate is produced. This compound is readily decomposed by sodium carbonate solution, producing a solution of sodium aluminate. Recovery of alumina from a sodium aluminate solution is a process of many years' standing, but details of the precipitation of alumina by a combined treatment with carbon dioxide and a "seed" charge of alumina are now being worked out at the Bureau of Mines' pilot plant.

The iron and silica in the primary alumina slag can be reduced to make the slag suitable for conversion into calcium aluminate, and the process as a whole is technically sound.

soft materials have a relatively high capacity for hardening by cold work. As a result of these differences in work-hardening capacity, as measured by the Meyer "n" value, materials of identical hardness according to one hardness scale may have substantially different hardness values when measured by another scale or by a different type of test.

In addition to the Meyer "n" determinations, the diameters of the Rockwell impressions were used as a basis for calculation Brinell hardness values. Brinell hardnesses corresponding to ratios of d/D (impression diameter/ball diameter) 0.1, 0.2, and 0.378, made with a $\frac{1}{16}$ in. diameter ball, were plotted against the diamond pyramid hardness values of the various alloys, and it was shown that the results were comparable when the ratio was about 0.375. Brinell hardness values calculated for ratios of L/D^3 of 5 and 30 with a $\frac{1}{16}$ in. diameter ball and 12.5 kg. and 76 kg., which were equivalent to loads of 500 kg. and 3,000 kg., with a 10 mm. diameter ball were also plotted against diamond pyramid hardness values, and compared with curves drawn from recent data for standard Brinell tests.

The correlation of diamond pyramid hardness and the various Rockwell scales is complicated by the fact that Rockwell tests are based on a system of measurement that differs considerably from that of diamond pyramid-hardness or other Brinell type tests. As a result of a special test carried out on duralumin and ingot iron, it was concluded that Rockwell values of materials with low work-hardening capacities (these materials having "ridging" type impressions) tended to be high as compared with materials having high work-hardening capacities (these materials having flat or "sinking-in" type impressions) even though these same materials might be of comparable hardness according to Brinell tests, in which the diameter of the indentation was measured.

Rockwell diamond pyramid hardness conversion relationships showed the influence of work-hardening to increase as the hardness increases. This follows from the fact that the load of 100 kg. used in the Rockwell "B" test produces very large impressions in the softer materials, and magnifies the work-hardening effect to a much greater extent than in diamond pyramid hardness tests or in Brinell tests. In Brinell tests it was found desirable to keep the ratio of d/D within the limits of 0.2 to 0.6,

Hardness Conversion Relationships

By R. H. Heyer

TO study the relationship between hardness scales based on pyramid and ball types of penetrators, tests were made on a variety of ferrous and non-ferrous materials including ingot iron, low-carbon steel, austenitic stainless steel, brass, duralumin, copper, a magnesium alloy and Monel metal, on surfaces, either cold-rolled, bright annealed, annealed and pickled or polished. The hardness tests carried out were Vickers' 10 kg., 30 kg., and 50 kg., Rockwell "B" and "F," and Rockwell superficial 45-T, 30-T, and 15-T. In addition to the standard procedure, the diameters of all Rockwell impressions were measured with the Vickers' microscope in order to establish work-hardening capacities of Meyer's analysis. Special Rockwell tests were also made to compare rates of flow under load in the hardness test.

Many materials having hardness in the Rockwell "B" range have the characteristics of flowing under load in the hardness test, so that the time factor must be controlled for each type of test before a consistent conversion can be expected. To determine the

importance of this factor, specimens of brass, duralumin, low-carbon steel and ingot iron were subjected to a series of load determinations from 5 to 120 secs., reading being taken every 5 secs. The results obtained showed mild steel and ingot iron to flow rapidly under load, and that the flow characteristic is not simply a function of hardness as very soft materials, such as brass, may resist flow. The Meyer "n" values for work-hardening of the four alloys also showed that flow was in no way related to work-hardening capacity.

To obtain the work-hardening exponent "n" by the Meyer analysis, the diameters of all Rockwell impressions were measured at 40 or 100 magnifications on the Vickers' tester, and "n" was obtained by plotting these diameters against the loads on logarithmic paper. The values of "n" were found to vary from approximately 2.0 for cold-rolled materials to 2.5 for some materials in the dead-soft condition. Materials that have been strain-hardened by cold-rolling have therefore a relatively low capacity for hardening by additional cold-work, whereas dead

and the equivalent ratio for the Vickers' penetrator was approximately 0.375 Rockwell impressions under about "B" 65 were found to have ratios of d/D over 0.6, Table I, on materials of high and low work-hardening capacities at three levels of diamond pyramid hardness. At the lower hardness levels, the Rockwell impressions made on the low work-hardening material specimens, A3 and D6, were appreciably larger than those in specimens B3 and S5 respectively, and this was properly reflected in the lower Rockwell hardnesses of A3 and D6.

The influence of work-hardening capacity was also found to be important when the relationships between Rockwell "B," Rockwell "F," and Rockwell superficial 45-T, 30-T, and 15-T scales were considered. A relationship existed with materials with high-work-hardening capacity (annealed) in the low Rockwell "B" range and with materials with low work-hardening capacity (cold-worked) in the high

TABLE I.—ROCKWELL D.P.H. CONVERSION RELATIONSHIPS.

	Monel Metal.	Rolled Copper.	Brass.	Aluminum Alloy.	Running Steel.	Aluminum Alloy.
D.P.H.	119	120	93	94	71	70
N	2.35	2.00	2.31	1.95	2.46	2.05
Rockwell B	68	65	50	38	33	7
d/D	0.59	0.65	0.66	0.76	0.69	0.84

Rockwell "B" range, but failed to provide for materials such as aluminum and some of its alloys which attain low Rockwell hardnesses only in their cold-worked or hardened states or austenitic stainless steels which have high Rockwell hardnesses in their dead-soft condition. The conversion relationships also showed that for Rockwell "B" 20 a range of about 10 points could be expected on the "F" scale, 25 points on the R 45-T scale, 21 points on the R 30-T scale, and 12 points on the R 15-T scale.

Creep Studies on Cupola Malleable Cast Iron

By J. J. Kanter and G. Guarneri

IN view of the apparent lack of creep information on malleable cast irons, a series of high temperature investigations were made on cupola malleable cast iron, and the data obtained discussed with certain other data pertinent to a critical evaluation on the metallurgical properties of the high-temperature usefulness of this alloy. Test bars for the various experiments were made from a white iron containing 3.16% total carbon, 2.98% combined carbon, 0.91% silicon, 0.47% manganese, 0.092% sulphur, and 0.17% phosphorus. After a malleablising treatment according to regular manufacturing practice, the total carbon was 2.78%, of which 0.005% was estimated from the microstructure to be combined as pearlite. Short-time and long-time high temperature tensile tests were carried out according to American Society for Testing Materials Standard Methods.

The malleable iron used for the investigations had a tensile strength of 19.4 to 21.9 tons per sq. in., a yield-point of 15.1 to 15.6 tons per sq. in., and an elongation of 6 to 7%

on 2 in. The results of short-time tensile tests including tensile strength, yield-point, proportional limit, elongation, and reduction of area from 0° to 540° C., together with values for Charpy impact strength, is measured by the keyhole notched bar, are shown in Fig. 1. Fifteen creep-time determinations were made representing a total of about 23,000 hours of testing, and from these curves creep-stress curves for cupola malleable cast iron in terms of total deformation per 10,000 hours for 0.1 and 1% total creep were drawn and are given in Fig. 2.

From the data obtained it is shown that at 425° C. cupola malleable cast iron has about two-thirds of the creep strength of silicon-killed carbon steel having a minimum tensile strength of 31 tons per sq. in. Above 425° C. and up to 540° C., the ratio between malleable iron and steel varies between one-half and one-third. An allowable

working stress for cupola malleable cast iron based on this data, using allowable working stresses established for steel as a comparison, would be 2.5 tons per sq. in. up to 415° C., at which temperature the creep strength of the cupola malleable cast iron is found to be about 67% as great as that accepted for carbon steel. A stress of 2.5 tons per sq. in. is two to four times as great as is used in present designs of pipe fittings for a maximum

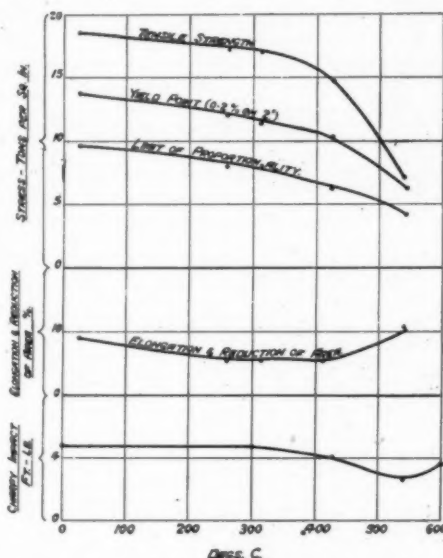


Fig. 1.—High-temperature properties of cupola malleable iron.

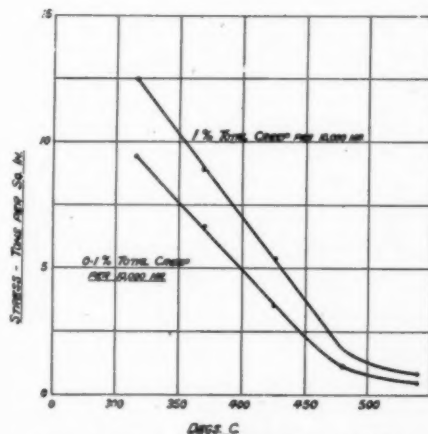


Fig. 2.—Creep stresses for cupola malleable iron.

service temperature of 230° C. (450° F.).

The stability of the properties of cupola malleable cast iron under creep condition were shown by its high temperature ductility-to-fracture properties, which indicated that not only

was the normal capacity to elongate retained, but at the higher temperatures 480° to 650° C. a considerable increase in ductility was found, showing excellent time-to-fracture strength. Tensile tests made on specimens after being creep tested to 540° C. showed malleable cast iron to retain good physical properties. There also appeared to be little change from the original structure, except for the evidences of working in over-stressed specimens and a tendency to complete graphitisation of residual pearlite.

The results obtained from the Charpy notched-bar impact tests showed that

the dynamic properties of malleable cast iron did not appear to be impaired by temperature. The same value was obtained from room temperature to well above 315° C., followed by a slight decrease beginning at 425° C., Fig. 1. The endurance limit of the malleable cast iron tested was found to be about 10 tons per sq. in.

An attempt was also made to estimate the permanent growth of cupola malleable cast iron incident to the creep deformation, and measurements were therefore made on certain of the creep specimens after removal from the test furnaces to differentiate

between the actual creep deformation and the amount of growth which occurred. From these measurements the linear growth was estimated, when it was found that no growth occurred up to 425° C. at stresses of the magnitude of interest for design purposes. At 485° C. and above, a slight growth appeared, attributable in part to the graphitisation of residual pearlite.

In general, the results of all the tests on cupola malleable cast iron at high temperatures indicated that the current engineering temperature limits on the use of this material appeared to be too conservative.

Thermal Expansion of some Industrial Copper Alloys

By Peter Hidnert and George Dickson

TABLE I.—COEFFICIENTS OF LINEAR EXPANSION OF SOME INDUSTRIAL COPPER ALLOYS.

Sam- ple.	Chemical Composition.									Treatment.	Average coefficients of expansion, ^a per Degree Centigrade.										Change in Length after Heating and Cooling ^b	
	Cu.	Ni.	Al.	Sn.	Zn.	Fe.	Mn.	Pb.	Si.		20° to 100° C.	20° to 200° C.	20° to 300° C.	20° to 400° C.	20° to 500° C.	20° to 600° C.	20° to 700° C.	20° to 800° C.	20° to 900° C.			
D.—MISCELLANEOUS COPPER ALLOYS.																						
1445	84.96	—	—	5.02	5.15	—	—	4.87	—	Cast rod.	$\times 10^{-6}$ d17.8	$\times 10^{-6}$ d18.1	$\times 10^{-6}$ d18.5	$\times 10^{-6}$ d18.9	$\times 10^{-6}$ d19.3	$\times 10^{-6}$ d20.0	$\times 10^{-6}$ d20.6	$\times 10^{-6}$ d21.2	$\times 10^{-6}$ d21.8	$\times 10^{-6}$ d22.4	+0.05	
1575	84.93	—	5.5	—	—	0.22	9.4	—	—	Cold-drawn wire, Imm. in diameter, baked in air at 140° C. for 18 hrs.	$\times 10^{-6}$ e18.1	—	—	—	—	—	—	—	—	—	+0.01	
1444A	84.84	—	—	14.95	—	—	—	0.21	—	Outside section (cross section, circular segment with $\frac{3}{8}$ in. rise) of $\frac{1}{2}$ in. diameter, cast rod.	$\times 10^{-6}$ d18.0	$\times 10^{-6}$ d18.2	$\times 10^{-6}$ d18.6	$\times 10^{-6}$ d18.8	$\times 10^{-6}$ d19.3	$\times 10^{-6}$ d19.8	—	—	—	—	-0.02	
1084	71	18	—	6	1	—	—	4	—	Bar $\frac{1}{2}$ in. by $\frac{1}{2}$ in. cross section, cast.	—	16.4	—	17.0	—	18.5	—	—	—	21.6	—	
1073	66.2	(f)	1.8	(f)	22.9	2.6	3.5	(f)	—	Rod $\frac{1}{2}$ in. in diameter machined from $\frac{1}{2}$ in. diameter casting.	18.7	19.8	20.8	—	—	—	—	—	—	—	-0.00	
897A	63.68	—	3.6	40.50	(j)	2.4	2.5-3	40.20	—	Extruded rod, $\frac{1}{2}$ in. diameter.	18.5	17.0	17.0	—	—	—	—	—	—	—	-0.13	
897AB	63.68	—	3.6	40.50	(j)	2.4	2.5-3	40.20	—	Same treatment as sample 897, then heated to 300° C. and cooled and aged at room tem- perature for 21 years.	19.0 e19.0	20.6 e20.5	21.3 e21.3	—	—	—	—	—	—	—	-0.00	
683	65	11	—	—	22	1.5	0.5	—	—	Cold-rolled and cold- drawn rod, $\frac{1}{2}$ in. in diameter.	k16.5	k17.0	k17.4	—	—	—	19.1	19.7	—	—		
1026	64.9	28.5	—	—	—	4.9	0.9	—	—	Bar $\frac{1}{2}$ in. by $\frac{1}{2}$ in. cross section, cast.	—	—	15.8	16.2	—	—	18.0	—	—	—	+0.01	
934I	64	—	—	—	—	—	—	34	—	Rod $\frac{1}{2}$ in. in diameter machined from sand casting.	k20.1	k20.0	k20.0	k19.9	k19.8	—	—	—	—	—	—	
280	63.60	13.18	—	—	g21.45	1.72	—	0.05	—	Rod $\frac{1}{2}$ in. in diameter, treatment not known.	17.2	17.5	18.0	—	—	—	—	—	—	—	-0.00	
281A	—	—	—	—	—	—	—	—	—	—	17.2 e17.4	17.6 e17.8	(n)	—	—	—	—	—	—	—	-0.00	
498	58.4	13.7	—	(f)	g23.5	0.22	0.13	(f)	—	Tube $\frac{3}{8}$ in. outside diameter.	17.4	—	17.8	18.3	18.9	—	—	—	—	—	-0.04	
682	55	32	—	—	7	6	—	—	—	Bar $\frac{1}{2}$ in. by $\frac{1}{2}$ in. cross section, cast.	k14.9	k15.4	k16.0	—	—	—	18.3	18.6	19.2	—	—	
621e	48.80	31.26	—	—	8.93	8.83	0.16	2.23	0.66	Bar $\frac{1}{2}$ in. by $\frac{1}{2}$ in. cross section, cast	—	15.4	16.1	16.6	17.1	17.6	18.2	18.9	—	—	—	
—	100	—	—	—	—	—	—	—	—	—	16.8	17.3	17.7	17.9	18.3	18.6	19.0	19.4	19.8	—	—	

^a The values indicated by asterisks were determined from the curves on cooling the samples from the maximum temperature to 20° C.

^b Determined from the expansion curve on heating and the contraction curve (or final observation) on cooling. The plus sign indicates an increase in length and the minus sign a decrease in length.

^c Reported by Hidnert and Sweeney [2] to the American Physical Society.

^d Reported by Hidnert [3] to the American Physical Society.

^e Reported on page 139 of publication by Thomas [4].

^f Not detected.

^g By difference.

^h Chemical composition within range specified by Federal Specification QQB721A, Class B, or Navy Specification 46B15, Class B.

ⁱ Maximum.

^j Remainder.

^k Computed from a second-degree equation derived from the observations.

^l Antimony 2%. After heating the sample to 500° C. and cooling to 20° C. incident to the thermal-expansion determinations, several small globules (probably lead) were found on the surface of the sample.

^m Duplicate of sample 280.

ⁿ Heating coil of oil bath burned out before observation could be taken at 300° C.

^o Carbon 0.41%. (Apparent total contents of elements 101.3%.)

^p Added for comparison with the copper alloys.

DATA obtained between 1916 and 1943 on the linear thermal expansion of some industrial copper-nickel, copper-nickel-aluminum, copper-nickel-tin, and miscellaneous copper alloys, are presented. Co-

efficients of expansion during the heating and cooling of the samples are given for various temperature ranges between 20° and 900° C. The length of each sample used in the determinations of linear thermal expansion was 300 mm. (11.8 in.). The cross-sections of the samples, their treatments, and chemical compositions are given in Table I.

Expansion curves on heating and on cooling were plotted from the observa-

tions made on the various samples. Coefficients of expansion and coefficients of contraction were obtained from these curves and are tabulated in Table I. This table also shows, for most of the samples, the permanent change in length that occurred as a result of the heating and cooling in the thermal-expansion tests.

The data on samples 1493 and 1493A and samples 1494 and 1494A indicate that the coefficients of expansion on a second heating are nearly the same as the coefficients of contraction during

the previous cooling. From these data and previous experience the authors believe that similar results will be obtained for most of the other copper alloys on a second heating. The coefficients obtained during the first cooling from the maximum temperature to 20° C. may therefore be used for repeated heating and cooling through this temperature range. However, if an alloy is repeatedly heated to only a moderate temperature, the coefficient of expansion during the first heating should be used.

From Jour. Res., U.S. Bureau of Standards, 1913, 31, No. 2, 77-82.

TABLE I.—COEFFICIENTS OF LINEAR EXPANSION OF SOME INDUSTRIAL COPPER ALLOYS.

Sample.	Chemical Composition.									Treatment.	Average coefficients of expansion, ^a per Degree Centigrade.										Change in Length after Heating and Cooling. ^b
	Cu.	Ni.	Al.	Sn.	Zn.	Fe.	Mn.	Pb.	Si.		20° to 100° C.	20° to 200° C.	20° to 300° C.	20° to 400° C.	20° to 500° C.	20° to 600° C.	20° to 700° C.	20° to 800° C.	20° to 900° C.		
A.—COPPER-NICKEL ALLOYS.																					
1489	96-06	3-02	—	—	—	0-12	—	—	0-61	Cast at 1,200° C. and machined to $\frac{1}{8}$ in. in diameter.	$\times 10^{-6}$ 16-6 17-0	$\times 10^{-6}$ 17-1 17-3	$\times 10^{-6}$ 17-5 17-7	$\times 10^{-6}$ 17-8 17-9	$\times 10^{-6}$ 18-2 —	$\times 10^{-6}$ 18-7 —	$\times 10^{-6}$ 19-2 19-0	$\times 10^{-6}$ 19-5 19-4	$\times 10^{-6}$ — —	% +0-01	
1490	96-06	3-02	—	—	—	0-12	—	—	0-61	Cast at 1,200° C., annealed at 850° C. for 3 hours, quenched in water, heat-treated at 450° C. for 3 hours, cooled slowly in air, and machined to $\frac{1}{8}$ in. diameter.	15-6 17-2	16-5 17-2	17-1 17-6	17-6 17-9	18-0 —	18-6 —	19-3 18-9	19-4 19-1	— —	+0-03	
1386	96-00	3-14	—	—	—	—	—	—	0-86	$\frac{1}{8}$ in. diameter rod annealed at 850° C. and quenched.	16-6 —	16-7 —	17-2 —	17-3 —	17-8 —	18-2 —	18-9 —	19-3 —	— —	—	
1395	95-71	3-22	—	—	—	—	—	—	0-69	Drawn from $\frac{1}{8}$ in. to $\frac{1}{16}$ in. in diameter.	16-9 —	17-0 17-1	17-7 17-5	18-0 17-8	18-3 —	18-7 18-3	19-1 18-6	19-9 18-7	— —	+0-10	
B.—COPPER-NICKEL-ALUMINIUM ALLOYS.																					
1491	89-67	4-47	5-04	—	—	—	—	—	0-82	Cast at 1,200° C. and machined to $\frac{1}{8}$ in. in diameter.	16-4 16-8	16-8 17-0	17-4 —	17-8 18-0	18-3 —	18-8 —	19-1 19-2	19-5 19-6	— —	+0-01	
1492	89-67	4-47	5-04	—	—	—	—	—	0-82	Same treatment as sample 1490.	16-7 16-8	17-1 17-1	17-5 17-6	18-1 17-9	18-6 —	19-5 —	19-2 19-0	19-1 19-4	— —	+0-02	
1493	89-67	4-47	5-04	—	—	—	—	—	0-82	Hot rolled at 750° C. from $\frac{1}{8}$ in. to $\frac{1}{16}$ in. in diameter, annealed at 800° C., quenched in water, drawn to $\frac{1}{8}$ in. in diameter, annealed, drawn to $\frac{1}{8}$ in. in diameter, annealed, drawn to $\frac{1}{8}$ in. in diameter, annealed at 850° C. for 3 hrs. and quenched.	17-0 16-6	16-8 17-1	17-2 17-5	17-8 17-9	18-3 18-2	19-0 —	19-5 18-7	— —	— —	— —	+0-05
1493A	89-67	4-47	5-04	—	—	—	—	—	0-82	Same treatment as sample 1493, then heated to 700° C. and slowly cooled.	16-8 16-5	17-0 17-0	17-4 17-4	17-9 17-9	18-3 —	18-5 —	18-7 —	19-1 19-4	— —	+0-03	
1494	89-67	4-47	5-04	—	—	—	—	—	0-82	Same treatment as sample 1493, then heat-treated at 450° C. for 3 hours and slowly cooled in air.	16-8 16-6	17-0 17-0	17-4 17-5	17-9 17-9	18-3 —	19-1 —	19-7 19-0	19-8 19-4	— —	+0-03	
1494A	89-67	4-47	5-04	—	—	—	—	—	0-82	Same treatment as sample 1494, then heated to 800° C. and slowly cooled.	16-6 16-4	16-9 17-1	17-3 17-5	17-9 17-9	18-2 —	18-7 —	19-0 19-1	19-3 19-5	— —	+0-01	
C.—COPPER-NICKEL-TIN ALLOYS.																					
1157	69-57	28-70	—	0-91	—	—	—	—	—	Rod $1\frac{1}{8}$ in. in diameter, extruded from $1\frac{1}{2}$ in. in diameter and finished hard, with a $\frac{1}{16}$ -in. draught after annealing.	15-2 —	15-4 —	16-3 —	— —	— —	— —	— —	— —	— —	+0-00	
1085	69-57	20	—	12	—	—	—	—	—	Bar $\frac{1}{2}$ in. by $\frac{1}{4}$ -in. cross section, cast.	— —	16-2 —	— —	16-9 —	— —	18-1 —	— —	22-9 —	— —	—	

The coefficients of expansion of the two copper-nickel-tin alloys containing 20 and 29% nickel are appreciably less than the coefficients of expansion of copper for temperature ranges between 20° and 600° C. For the range 20° to 900° C. the coefficient of expansion of the copper-nickel-tin alloy containing 20% nickel is about 16% higher than the coefficient of expansion of copper.

The substitution of 5% zinc and 5% lead for 10% tin in the bronze containing 15% tin caused slight changes in the coefficients of expansion. The

three miscellaneous alloys (samples 1026, 682, and 621) containing more than 28% of nickel show the smallest coefficients of expansion of this group in Table I. The coefficients of expansion (or contraction) of samples 1073, 897, 897A, and 934, which do not contain nickel, are the largest of the alloys investigated. The coefficients of the latter four samples exceed the coefficients of expansion of copper, and the coefficients of expansion of the former three alloys are less than the coefficients of expansion of copper.

Low-Temperature Joining

By R. S. Burpo, Jr.

WELDING is accomplished by the use of enough heat to cause fusion of the rod with the materials being joined. The higher the temperature necessary to make the weld, the greater are the stresses set up in the parts being joined, and this leads to distortion. If lower temperatures must be used in order to avoid distortion, then as far as iron and steel are concerned only brazed joints can be made and these low-temperature brazed joints are usually much weaker than the parent metal. In a strong weld made at high temperature, the higher the temperature, the greater are the stresses produced by welding, and the greater is the softening or tempering effect if the steel has been hardened, while in a low-temperature joint stresses are low, little softening of hardened steel occurs, but the joint is usually lacking in physical properties.

To produce joints as strong as conventional fusion welding, but at temperatures in the brazing range, where distortion and unwanted tempering can be minimised, a series of low melting-point brazing alloys has been developed. One member of this series, in particular, is of interest, in that it is not only a low-melting point material, but the joints made with this rod have very favourable physical properties, and its flow temperature is so low that hardened high-speed steel parts can be joined with only one point Rockwell C loss of hardness. Some other items in this series of proprietary brazing rods (Castolin Eutectic) include some very low-melting materials, and rods that will match the colour of the parent metal.

As Castolin Eutectic products are new in the industrial field, their applications are somewhat limited, but their use is being rapidly extended. Each rod functions best with a particular flux, which means that an assortment of fluxes must be kept on hand if any variety of rods are used. Brazing techniques with those rods are also somewhat different than those used with other rods, but are easily learned. Three types of work to which the more unique metal-joining alloys have been applied with considerable success are: (1) The production joining of small parts; (2) repairing casting defects and repairing wrought parts; and (3) the repairing of broken tools and cutters. When using the alloys for these different types of work, the rods in combination with its special flux produces a metallic joint at a very low temperature. The mechanism of this low-temperature joining process is not generally understood, but the claim is made that the joint is of eutectoid or quasi-eutectoid composition. The relatively low temperatures at which these parent rod metal eutectoid joints are found is, perhaps, their most valuable property.

Experience gained in the salving of defective sand-cast aluminium and magnesium alloy parts indicate that the ease of welding delicate castings (where high temperatures and consequent distortion would be intolerable) and colour matching between the joint and parent metal are of primary importance. Aluminium castings which have cracked on cold straightening or which have minor defects in castings or placing the cores so that the part has insufficient allowance for machining are reclaimed, using a rod consisting

of an aluminium base having a bonding temperature of 510° C. Castings having sections varying from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. are preheated, and sufficient weld metal deposited using the special flux and an oxy-acetylene torch. Excess metal is removed by machining. A somewhat similar procedure is followed with sand-cast magnesium alloy parts, where the welding rod is an alloy containing over 90% magnesium.

Using a nickel-copper alloy rod which has a bonding temperature of 700° C., broken tools can be joined and high-speed tips brazed into carbon tool steel shanks in a very economical manner. This high-strength low-flow-temperature brazing technique has proved of particular value in the salving of high-speed melting cutters. In the repairing of such cutters which have been broken or cracked, the damaged tool is taken directly from service, the edges to be joined are chamfered, cleaned, and brazed, slowly cooled, and then, after grinding on a tool and cutter grinder is ready for service. By using these techniques, the distortion of repaired cutters is less than 0.001 in. and the reduction in hardness next to the joint is usually limited to one point Rockwell C.

Production ordnance parts have also been successfully joined by the use of Castolin Eutectic rods and have passed rigid service tests. With certain stainless steel parts the fabricating time is cut in half and the number of operations is reduced from 6 to 5, with no reduction in quality. Chromium-molybdenum steel supports (S.A.E.—4,130 steel) formerly fabricated in 20 mins. can be finished in 3 mins. A machine-gun sight has had its assembly time cut in half, using a nickel-copper rod as compared with the original silver soldering method.

In general, the properties of the nickel-copper alloy rod which have made it highly useful in many industries are its ease of application, in that the molten brazing material seems to have a very high mobility and will flow into very narrow spaces, making a very complete joint with a minimum of time and rod. The strength of the brazed joint obtained is at least equal to that of the parent metal, and in some tests the steels have fractured, leaving the brazed parts undamaged. Nickel-copper alloy rods have been used most successfully for joining stainless steel, chromium-molybdenum steel, and high-speed steel parts, and for brazing carbide tips into tool shanks and into milling cutters.

Creep Characteristics of Some Copper Alloys at Elevated Temperatures

By H. L. Burghoff, A. L. Blank
and S. E. Maddigan

THE results are given of creep tests on seven wrought copper alloys, including 70-30 brass, silicon-bronze (3% silicon), 85-15 brass, naval brass, Admiralty brass, phosphor bronze (5% tin), and 70-30 copper-nickel. The composition of the various alloys together with their temper are given in Table I. These alloys were prepared in the tempers shown to permit evaluation of the effect of grain size in annealed tempers and of degree of reduction in drawn tempers. Tests were made on wire drawn in coils to the final diameter, 0.125 in., and then mechanically straightened and cut to proper length. The materials to be tested in the annealed or soft condition was annealed in these straight lengths in order that they might be subjected to a minimum of distortion before actual testing started.

The creep tests were carried out at 150°, 205°, and 260° C. upon 0.125 in. diameter wire specimens with gauge lengths of 10 in. in three specially designed, forced convection, multiple specimen furnaces which permitted the simultaneous testing of several specimens at one time. The physical properties of all the alloys were determined before and after exposure in creep tests, and specimens were examined microscopically for any indication of sub-surface oxidation or deterioration and in the case of hard-drawn tempers, of recrystallisation or softening. Creep specimens were suspended in the furnace for 24 hours before loading. Initial extensions were observed and then readings were made at suitable intervals to define the course of the time-extension curve, the duration of the tests being of the order of 5,000 hours. The normal creep curves obtained were analysed according to the formula—

$$\text{Creep} = e_0 vt$$

where e_0 = a constant, v = the creep rate, and t = time. The creep rate was taken from the second stage of the creep curves, where the rate of creep was constant or only decreasing slightly.

The relationships between stress and creep rate for 70-30 brass at 150°, 205°, and 260° C. were plotted logarithmically and showed the original temper of this alloy to be a very important factor in determining its creep characteristics. At 150°, 205°, and 260° C. creep resistance of annealed material increased as grain size increased within the range of normally encountered grain sizes, and the grain size effect was similarly noticeable in drawn materials. In addition, the degree of cold working in hard materials was important, for it was intimately associated with recrystallisation at 205° and 260° C. A coarse-grained alloy might show nominally high-creep strength for conditions under which it was becoming embrittled by intergranular separation and hence might be in danger of sudden failure. The results obtained also indicated that the lowest possible recrystallisation temperature of 70-30 brass might be below 150° C. if the relative positions of the stress-creep curves for fine and coarse-grained annealed materials be a criterion.

At 205° and 260° C., the annealed silicon-bronze with grain size of 0.100 mm. had higher creep strength than that with grain size of 0.008 mm. There was little difference in creep strength as drawn 37 and 84% at 205° C., but at 150° C. the harder drawn material became superior for

high stresses in a manner similar to that for drawn 70-30 brass at the same temperature. At 260° C., the hardest material drawn 84% had the least creep strength of all the tempers, and at 150° and 205° C. the alloy was better as drawn than as annealed, but recrystallisation effects lowered the relative positions of the drawn tempers

TABLE I.—COMPOSITION AND TEMPERS OF ALLOYS TESTED.

Alloy.	Composition.									Temper.
	Cu.	Zn.	Sn.	Si.	P.	Fe.	Mn.	Ni.	Pb.	
70—30 Brass.	70.45	29.54	—	—	—	0.01	—	—	0.05	(a) Annealed 0.200 and 0.022 mm. grain sizes. (b) Drawn 37% and 84% (coarse-grained).
Silicon bronze	96.34	0.80	—	2.80	—	0.06	—	—	0.005	(a) Annealed 0.100 and 0.008 mm. grain sizes. (b) Drawn 37% and 84%.
8—15 Brass.	84.79	15.20	—	—	—	0.004	—	—	0.002	(a) Annealed 0.060 mm. grain size. (b) Drawn 37% and 84%.
Naval brass.	59.98	39.35	0.65	—	—	0.015	—	—	0.05	(a) Annealed at 540° C. (b) Drawn 37%.
Admiralty brass.	71.06	27.99	0.92	—	—	0.008	—	—	0.015	(a) Annealed 0.055 mm. grain size. (b) Drawn 60%.
Phosphor bronze.	94.16	—	5.56	—	0.24	0.01	—	—	—	(a) Annealed 0.050 mm. grain size. (b) Drawn 84%.
70—30 Copper nickel	69.07	—	—	—	—	0.03	0.80	30.06	0.005	(a) Annealed 0.02 mm. grain size. (b) Drawn 84%.

at 260° C. No change in structure or properties for any of the tempers were observed after exposure at 150° C., except for a slight increase in tensile strength of the wire drawn at 84%. Wire so drawn was also found to have recrystallised to a very small grain size at 260° C., which accounted for its low creep resistance at this temperature. It did not recrystallise or soften at 205° C., or did that drawn at 37%.

The 85-15 brass was investigated as annealed with grain size of 0.060 mm and as drawn 37 and 84%. At 150° C. the order of merit of the three tempers was as drawn 84%, as drawn 37%, and as annealed, and the difference between the first two tempers was marked. The 37% draw proved to be the most resistant temper at 205° C., while the 84% was the least resistant. The 37% draw was also superior to the 84% draw at 260° C., but no data was obtained on the annealed alloy at this temperature. For stresses of 0.44 and 1.35 tons per sq. in. at 260° C., the creep rates of this alloy drawn 37% increased initially, then decreased and became substantially constant, but when stressed at 2.7 tons per sq. in. the course of creep was normal and the third stage soon developed and was normal for the duration of the test. These phenomena were quite similar to those for 70-30 brass drawn 37%

at 205° C., and to those for silicon bronze drawn 37% at 260° C., and the underlying cause, recrystallisation and softening, was the same. There was no significant change in structure or tensile properties of the alloy as originally annealed or as drawn 37% after tests at 150° and 205° C. Recrystallisation in 85-15 brass as drawn 84% was complete after 8,980 hours at 205° C., and after 3,900 hours at 260° C.

Naval brass was investigated as annealed at 540° C., and as drawn 37% and the stress-creep rate curves for the two tempers were found to intersect at both 150° and 205° C. There was no significant change in properties of either temper after testing at 150° C. except for slight change in elongation. After exposure at 205° and 260° C., the tensile strength of the annealed material was unchanged, but the elongation in the tensile test decreased. The drawn material was partially recrystallised at 205° C., and at 260° C. there was further softening, and recrystallisation appeared complete. Creep data obtained on Admiralty brass after annealing, and after drawing at 60%, showed the drawn alloy had recrystallised at 260° C., and was behaving as a fine-grained annealed material.

The stress-creep rate data obtained for the annealed and drawn phosphor bronze showed the creep rate of the annealed material at 150° C. to be very low, and lower than for the drawn temper for stresses of 7 tons per sq. in. or less. Comparison of the two tempers at 205° C. was difficult because of the lack of sufficient data, and at 260° C. the annealed condition was easily the better of the two. The structure and tensile properties of the annealed phosphor bronze were essentially unaffected at all three temperatures. The drawn alloy was partly softened at 205° C., although there was no indication of recrystallisation in the microstructure, and at 260° C. recrystallisation was practically complete after 2,200 hours.

The creep-rate of the 70-30 copper-nickel alloy as annealed was almost negligible at 150° C. for stresses of 8.9 tons per sq. in. or less, and at 260° C. the creep rate was only 0.0054% for 1,000 hours at 11.7 tons per sq. in., a stress for about the yield strength of alloy at this temperature. At 260° C., the creep resistance of the drawn material was exceptionally good, and although the rate was greater than for the annealed alloy for stress below 4.45 tons per sq. in., it was

much superior at higher stresses. A stress of 18.2 tons per sq. in. produced a creep rate of only 0.0035% per 1,000 hours after 4,800 hours. There was no significant change in the structure or tensile properties of this alloy either as annealed or as drawn after testing at either temperature and it did not recrystallise at all at 260° C.

The data obtained showed the 70-30 copper-nickel to be the best of the alloys tested for service at elevated temperatures. Quantitative comparisons of the creep resistance of the other alloys were difficult to make because of the importance of the factors of grain size for annealed tempers and of both grain size and degree of final reduction for cold-worked tempers. In general, however, the Naval brass was inferior to 70-30

brass, and the silicon bronze definitely, and the Admiralty brass and the phosphor bronze slightly superior to 70-30 brass. The 85-15 brass was in some respects better than the 70-30 brass. It was also shown that the creep resistance of those alloys finished by a cold-working operation was largely determined by their recrystallisation characteristics. If they recrystallised within a short time at elevated temperature, they behaved as annealed materials, and, if recrystallisation took place over a prolonged period, the materials were very unstable as regards to creep. If no recrystallisation occurred, creep resistance might be high, but intercrystalline parting might embrittle the metal. Grain size was also found to be an important factor in determining creep resistance.

Beryllium Copper for Wire and Strips

By H. G. Williams

TO gain the advantages that beryllium copper offers in spring applications, the material must be (a) of suitable quality, and (b) properly heat-treated. Every coil of wire and every lot of strip has a particular precipitation hardening time-temperature requirement depending upon its past history and the future of its use. Many of the more critical uses of beryllium copper are only possible if the very best quality of material is used and the precipitation hardened at the precise temperature and time to develop the specific properties required for the application. Some springs require maximum hardness or strength, others minimum drift or maximum stability, high conductivity or controlled ductility. The emphasis varies with each design and thus affects the heat-treatment required.

One important advantage gained from using beryllium copper is the opportunity to make parts from soft, readily formed material which can be hardened after forming to give superior spring qualities. However, the final spring properties obtained from the heat-treated material are increased by cold work. Therefore it should be work-hardened the maximum possible amount before forming and yet be successfully formed. Severe cold working while greatly improving the physical properties obtainable by precipitation hardening introduces a loss in the stability of the parts unless hardened at a higher temperature

(343° to 371° C.) than usually used and for a shorter time (10 to 15 mins.). Test methods are based on the metallurgy of the commercial beryllium copper alloys. These alloys contain 1.9 to 2.2% beryllium, with not over 0.5% nickel or cobalt added to control grain growth, not over 0.5% iron, silicon or other impurities, and the balance copper. After casting, beryllium copper ingots are usually hot worked in the range of 593° to 760° C. This gives a duplex structure of alpha and beta phase which is homogenised by a solution heat-treatment of several hours at 788° C., followed by a rapid quench in water. The alloy is then cold-worked, being annealed rather often since it work-hardens rapidly. It is annealed by a short heat-treatment at 788° C., followed by a rapid water quench after each anneal. At this stage the structure consists of super-saturated alpha phase plus some undissolved beta crystals.

Beryllium copper is also processed by a method designated as "homogenised," which, up to the final anneal, results in a fine three-phase mixture of alpha, beta and gamma. This condition is obtained by heating the alloy at a temperature under 566° C. for several hours and air cooling to room temperature. It is then cold-worked in this condition. The "homogenised" structure must be annealed at the solution temperature and quenched before it is rolled or drawn to final temper to make it respond to the hardening heat-treatment. After forming, the part is precipitation-hardened

in the range from 316° to 371° C., the time ranging from an hour or more at the lower temperature to a few minutes at the higher temperature. During this heat-treatment the supersaturated alpha phase precipitates its excess beryllium in the form of gamma phase, which gives the material its desirable hardness and strength.

The physical properties of these various phases which are of the most use in determining the quality of wire are electrical conductivity and tensile strength. For strip it is more convenient to measure hardness instead of tensile strength. The advantages of

using these tests are the speed and accuracy with which both the quantity and the proper heat-treatment can be determined. The conductivity is obtained by measuring the resistance of a convenient length of wire, such as 3 ft. (91 cm.), with a Wheatstone bridge. Tensile strength of hardened and unhardened wire is measured in conventional manner on a commercial machine. A small neutral salt-bath furnace maintained at the heat-treating temperature by automatic temperature controls is required for the hardening operation.

The Effect of Heat-Treatment on the Magnetic Properties of Iron and Manganese-Rich Minerals

By Gust G. Bring

THE magnetic properties of many iron and manganese rich minerals are altered by a single heat-treatment to an extent which allows a considerable improvement in the efficiency of magnetic methods of ore separation and handling. The presence of a reducing agent during the treatment

3% FeHCl; "green mineral" (4% Mn, 14% FeHCl), and dolomite (11% Mn, 3% Fe) from Tuna Hästberg, and dolomite from Klackberg (7% Mn, 11% Fe).

The material was crushed to a grain size of 0.2-0.5 mm., and the magnetite removed by magnetic separation.

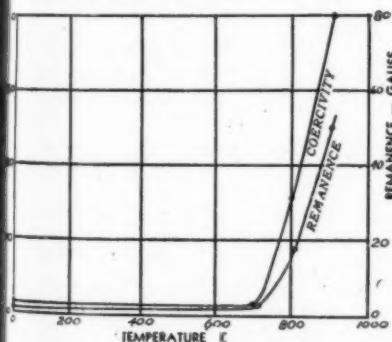


Fig. 1.—Effect of heat-treatment for 1 hour on coercivity and remanence. Mineral Grunerit from Bastkärn.

brings about a further improvement in some cases.

In the present experiments a number of manganese-rich minerals, together with specimens of magnetite and iron pyrites for comparison, were heated at various temperatures from 500° to 900° C. for 1 and 2 hours in air. The minerals examined were: *Knebelit*, from Tuna Hästberg, Bastkärn and Stollberg, containing 12-20% Mn and 27-37% HCl-soluble Fe; *grunerit*, from Bastkärn, containing 6% Mn, 32% FeHCl; granite (16% Mn,

The measurements were carried out with the Gottschalk Davis apparatus,¹ which consisted in principle of a strong electromagnet with polepieces 13.3 mm. apart. In the air gap, capsules containing the mineral could be inserted.

The capsules were made of brass, with soft sheet-iron circular ends, which were screwed in to compress the powders. The capsules had windings connected to a ballistic galvanometer. The tightness of packing and grain-size influence the susceptibility and coercive force, and these were standardised as far as possible.

The results were as follows:

Knebelit and *grunerit* showed increased susceptibility after heating at 800° C. for 1 hour, and the curves of coercivity and remanence showed a sharp upward movement above 700° C. for both 1- and 2-hour treatments. The curves for *grunerit*, after a 1-hour treatment, are shown in Fig. 1.

The granite and "green mineral" samples became paramagnetic after heating at 900° C. The $H/4\pi I$ curve for granite is shown in Fig. 2. Coercive force could only be retained on heating to 900° C. by making 3% additions of carbon. Granite showed an inconsiderable rise in volume susceptibility on heating to 900° C. With dolomite from Tuna Hästberg, no change was observed on heating to 900° C., apart from the loss of carbon dioxide. The dolomite from Klackberg, which had a higher iron content, probably in the form of carbonate, showed an interesting alteration round about 700° C. The susceptibility rose to 3-5 times the original value. At higher temperatures it returned to normal. By heating this dolomite with carbon the value increased over the same temperature region, probably on account of the formation of magnetite.

Experiments were then made on the behaviour of these materials in unidirectional and alternating field magnetic separators. The unidirectional field separator chiefly used was that described by Granigg.² It consisted of a cylindrical iron case G (Fig. 3) with pole pieces W capable of producing a magnetic field of 14,000 oersted. The magnetic particles were carried along by the Archimedean screw to *a*, whilst the non-magnetic fraction falls through *D*.

Numerous separators making use of the movement produced in magnetisable particles by an alternating magnetic field have been described in the literature since 1910 (see e.g. ^{3,4}).

In these experiments a separator similar to that of Dean and Davis⁵ was used.

This is shown diagrammatically in Fig. 4. A belt runs at 30° to the main direction, starting from the position of the magnet, and carries off the magnetisable particles. A 3-phase 50-cycle supply was used. The experiments showed that the *knebelit*, granite and dolomite were all strongly attracted by the fields used in the

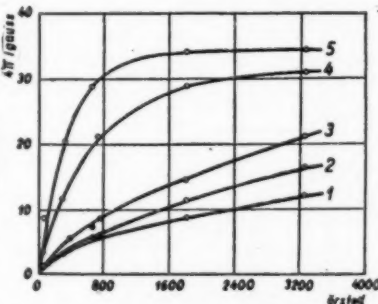


Fig. 2.—Granite from Tuna Hästberg.

From *Jernkontorets Annaler*, vol. 127(9), 1943, pp. 447-49.

¹ V. H. Gottschalk and C. W. Davis. Investigation No. 3268, U.S. Dept. of Interior, 1935, p. 5.

² B. Granigg. *Metall u. Erz.*, **34**, 1937, p. 280; *Archiv. f. Erzbergbau, Erzverarbeitung, Metallhüttenwesen*, 1931, p. 76.

³ C. W. Davis. Investigation No. 3268, U.S. Dept. of Interior, 1935.

⁴ E. W. Schilling and H. Johnson. *Metals Technology*, **2**, 1935, TP 654.

⁵ R. S. Dean and C. W. Davis. *Trans. Amer. Inst. Min. Met. Eng.*, **112**, 1934, p. 809.

Granigg separator, and also in a much weaker laboratory model. Granite was attracted somewhat better after heat-treatment.

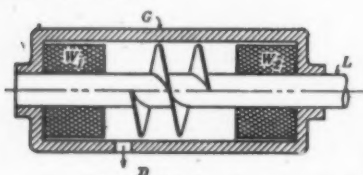


Fig. 3.—Magnetic separator (Granigg).

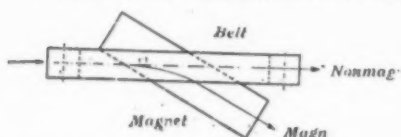


Fig. 4.—Alternating field separator.

With the alternating field apparatus the attraction of *knebelit* increased strikingly after heat-treatment, as is to be expected from the above experiments.

Granite and dolomite were very little affected by the available field strengths, before and after heat-treatment.

For comparison, it may be mentioned that untreated iron pyrites was only weakly affected by a strong unidirectional field, but strongly by the alternating field separators.

A list of 73 references is given in the original article.

Corrosion of Iron by Ammonia

By H. J. McDonald and M. Feller

AQUA ammonia solutions of concentration greater than 1% (one part of 15 NH_4OH per 100 parts of water) completely prevent the corrosion of iron in the form of steel wool. In solutions ranging downward in concentration from 1% there is increasing susceptibility to corrosion. This tendency, however, is still relatively small at 0.1% concentration. There is evidence of protective film formation, since steel wool which was exposed first to more concentrated NH_4OH solutions, then to very dilute solutions from which the NH_3 was allowed to escape, showed no tendency to rust. This is in contrast to the slight but definite tendency to rust of the steel wool in the regular very dilute solutions. The extensive rusting in the case of an altered 50% NH_4OH solution may be explained by assuming that slight "wounds" in the oxide film were caused by rinsing. Since not even a small amount of NH_4OH was added which would have "healed" the wounds, the infection was able to spread until the whole body was affected by the solution.

The iron used was clean steel wool of the regular commercial variety. The ammonia solutions were made from concentrated C.P. quality, ammonium hydroxide (15 N. or 28% NH_3) and distilled water. Since NH_4OH in aqueous solution is a weak electrolyte, the approximate concentration of hydrogen ion present in the several solutions may be calculated, using the Arrhenius equation for the ionisation of ammonium hydroxide, and the known value of the ionisation constant. The pH value of the solutions may then be computed. The procedure used was as follows: 11 ml. of solution was made up in a 250 ml. Erlenmeyer flask. A small wad of steel wool was introduced into the flask, where it lay approximately 75% submerged and 25% exposed to the "air + NH_3 mixture" above the solution surface. The flask was then stoppered and the solution swirled so as to wet the steel wool completely. The flasks were then allowed to stand at room temperature for a period of two to four weeks.

Desirable Features in a Blast Furnace

By John S. Stewart

FEATURES in a blast furnace which are expected to obviate many operating difficulties now experienced, and contribute to smooth, fast and economical smeltings, are summarised as follows:—

1. The shape should be such that would discourage the formation of shelves, arches and accretions.
2. The wider furnace at the tuyeres is preferred.
3. A large reserve of coke should be present at the tuyeres.
4. A large volume of air of sufficiently high pressure; distributed evenly at the tuyeres, in order to get deep penetration of the blast, a hot localised smelting zone and high CO concentration.
5. The smelting zone should be confined to the lower part of the furnace—not high in the shaft.
6. A large space for storage of slag so that reduction will be complete and there will be sufficient time for settling of metal and matte particles.
7. A non-slugging design of tuyere.
8. High velocity of gases in the shaft to remove excess fines and give less opportunity for ascending volatile matter to condense in the furnace.
9. Rapid subsidence of the charge in the shaft.
10. A short shaft, so the charge will pass to the smelting zone before it has reached the sticky, semifused state,

and the coke will be allowed to burn only in the lower part of the furnace.

11. A small area shaft to prevent segregation of the charge ingredients, thereby maintaining the mixture.

The author then describes and shows drawings of a type of furnace which would seem to meet these requirements. It is the direct opposite in many ways of the conventional type of blast furnace. Instead of having a contracted smelting zone, with a contracted tuyere diameter or width and an outwardly flaring bosh giving a large volume in the shaft and a large area at the charge floor, this furnace presents a large area at the tuyeres, an enlarged smelting zone at the bottom of the furnace, and a small area in the shaft. The slant of the lower jackets forms the inverted bosh, and, with the shaft, the shape of a circular furnace would be that of an inverted funnel. The lower jackets form a hollow truncated cone, with the vertical shaft of the small truncated cross-section diameter extending to the charge floor. This blast furnace, in the author's belief, holds promise of superior smelting of sinter, grey slags, drosses, refinery by-products, mattes and ores, as done in lead and copper smelters. Also, because of the intensified smelting zone and large hearth volume provided, the furnace should be valuable in smelting highly refractory ores, in fuming zinc from lead furnace slags, and as a foundry cupola.

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